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Probabilistic Assessment of Tornado-Borne Missile Speeds

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September 1980

Prepared for:

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Washington, D.C. 20555

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ERRATA

In Equation 13, delete: $i = 1$, $j = 1$; $k = 1$; $\ell = 1$; N_1; N_L; N_j; N_4.

Immediately following Equation 13, insert sentence: Where the summation extends over those values of i, j, k, and ℓ that are simultaneously associated with hitting missile speeds greater than V_m^{max}.

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U.S. DEPARTMENT OF COMMERCE, Philip M. Klutznick, ***Secretary***
Luther H. Hodges, Jr., ***Deputy Secretary***
Jordan J. Baruch, ***Assistant Secretary for Productivity, Technology, and Innovation***
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, ***Director***

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1. INTRODUCTION

Estimates of tornado-borne missile speeds for nuclear power plant design purposes were previously presented by the writers in Ref. 1. One of the assumptions on which these estimates were based was that the missiles start their motion from a point located on the tornado translation axis, at a distance upwind of the tornado center equal to the radius of maximum circumferential wind speeds. In addition, it was assumed in Ref. 1 that the speed with which a missile hits a target is equal to the maximum speed, denoted by V_H^{max}, that the same missile would attain if its trajectory were unobstructed by the presence of any obstacle.

Clearly, neither of these assumptions is realistic. The purpose of this report is to attempt an approach to the missile speed problem that takes into account the fact that the initial positions of the missiles with respect to the tornado center are not necessarily those assumed in Ref. 1, and that the speeds with which the missiles hit the targets are not necessarily equal to V_H^{max}.

2. APPROACHES TO THE PROBABILISTIC STUDY OF MISSILE SPEEDS

Estimates of tornado-borne missile speeds corresponding to a specified probability of occurrence must take into account a large number of factors, including: rate of occurrence of tornadoes at the geographical location of concern; tornado wind field; number, location, and physical characteristics of potential missiles, including aerodynamic characteristics; nature and magnitude of forces opposing or inducing missile take-off; and location and configuration of potential targets.

One possible approach to a probabilistic study of tornado-borne missile speeds is the use of Monte Carlo techniques in conjunction with probability distributions of the various parameters characterizing the factors listed above. Such an approach would involve a volume of computation that is likely to be enormous indeed. Moreover, many of the pertinent probability distributions are not, or are still only poorly, known. The writers believe that an exhaustive Monte Carlo approach of the type outlined above might be warranted for long-term research purposes, particularly if significant improvements are anticipated in the probabilistic modeling of the various factors involved. However, for the present, it is the writers opinion that much of the probabilistic and physical modeling of tornadoes and tornado-borne missiles that has evolved since the publication of Ref. 1 is not sufficiently well established to be relied upon confidently in the study presented herein.

For these reasons, the objective of this investigation has been limited to attempting a comparison between the speeds estimated in Ref. 1 on the one hand, and hit speeds obtained on the basis of the assumptions listed below, on the other hand:

1. The models used in Ref. 1 are correct with respect to (a) the probabilistic behavior of the tornado wind speeds, (b) the tornado wind field, and (c) the aerodynamic behavior of the tumbling missiles.

2. The number, geometry, and location of the potential targets is specified.

3. A specified number of missiles with specified properties and locations are present at the nuclear power plant site at the time of the tornado strikes, i.e., a "missile set-up" is specified. Alternatively, several possible missile set-ups are specified, each associated with a specified probability of occurrence, the sum of these probabilities being unity.

4. A specified area over or near the nuclear power plant is swept by tornadoes with specified wind speeds, to which there correspond probabilities of occurrence consistent with the estimates of Ref. 2.

5. Each missile starts its motion when the tornado-induced aerodynamic force, F_a, acting upon the missile at rest is such that

   $$F_a > F \qquad (1)$$

   where F = specified force. For convenience, the value of F is specified via a coefficient, k, in the relation

   $$F = kmg \qquad (2)$$

   where m = mass of missile, and g = acceleration of gravity.

3. PROBABILITIES OF OCCURRENCE OF TORNADOES

Consider some point A within a nuclear power plant site. Let the event, T, that a tornado will hit point A, and the event, (T, V_{torn}), that the point A will be hit by a tornado with maximum speeds larger than V_{torn} be denoted by $P_A(T)$ and $P_A(T, V_{torn})$, respectively.

Assume first, for the sake of simplicity, that the direction of the tornado axes of translation is fixed. Point A will be hit by a tornado only if the distance, L, from point A to the tornado axis of translation is $L < b/2$, where b = tornado path width (Fig. 1). An additional condition is that the distance, M, (along the axis of translation) between point A and the center, C, of the tornado path area be $M < d/2$, where d = tornado path length (Fig. 1). The following relation holds:

$$P_A(T, V_{torn}) = \int_{-d/2}^{d/2} \int_{-b/2}^{b/2} P_A'(T, V_{torn}, m, \ell)\, d\ell\, dm \qquad (3)$$

where $P_A'(T, V_{torn}, m, \ell)\, dm\, d\ell$ = probability of occurrence of a tornado such that the center of its path is inside the elemental area $d\ell\, dm$.

The effect of a tornado upon the trajectory of a given missile that it is going to pick up is clearly dependent upon the distance between that missile and the tornado axis of translation. On the other hand, if Eq. 1 holds, the effect of the distance betweem the missile and the center C is in most cases unimportant. Indeed, this effect is significant only if $M \simeq -d/2$. The tornado path length, d, being of the order of 10 km, the probability that $M \simeq -d/2$ is relatively small. Therefore, the influence of M upon the probabilistic estimates of missile hit speeds will generally be small.

Denoting the marginal distribution of P_A' with respect to m by P_A, Eq. 3 is written as

$$P_A(T, V_{torn}) = \int_{-b/2}^{b/2} P_A(T, V_{torn}, \ell)\, d\ell \tag{4}$$

where $P_A(T, V_{torn}, \ell)\, d\ell$ probability of occurrence of tornadoes that strike point A and have axes of translation crossing the segment $d\ell$, the midpoint of which is at a distance ℓ from A (Fig. 2a). In terms of discrete probabilities, Eq. 4 is written as

$$P_A(T, V_{torn}) = \sum_{i=1}^{N_1} P_A(T, V_{torn}, L_i) \tag{5}$$

$$P_A(T, V_{torn}, L_i) = \int_{L_i - \Delta L/2}^{L_i + \Delta L/2} P_A(T, V_{torn}, \ell)\, d\ell \tag{6}$$

and

$$N_1 = \frac{b}{\Delta L} \tag{7}$$

$P_A(T, V_{torn}, L_i)$ is the probability of occurrence of tornadoes that strike point A and have axes of translation crossing the segment ΔL, the midpoint of which is at a distance L_i from A (Fig. 2b). Since it is reasonable to assume that the probability of occurrence of tornadoes across the distance b is uniform,

$$P_A(T, V_{torn}, L_i) = \frac{1}{N_1} P_A(T, V_{torn}) \tag{8}$$

Let now the probability that point A will be struck by tornadoes with maximum wind speeds included in the interval $(V_{torn} - \Delta V_{torn}, V_{torn} + \Delta V_{torn})$ be denoted by $p_A(T, V_{torn}) \Delta V_{torn}$. Tails of probability density functions $p_A(T, V_{torn})$ can be estimated from the results of Ref. 2, as shown in Appendix AI.

n additional assumption used in this work pertains to the choice of the width b. The estimates of probabilities of occurrence $P_A(T)$ and $P_A(T, V_{torn})$ given in Ref. 2 are based, for any geographical location, upon the average individual tornado area, $\bar{a}$ (or, equivalently, upon the product of the average tornado path length, $\bar{d}$, by the average individual tornado path width, $\bar{b}$. For consistency with the estimates of Ref. 2, it is assumed in this report that if V_{torn} is equal to the maximum wind speed of the Design Basis Tornado [2], then to a probability $P_A(T, V_{torn}) = 10^{-7}$/year there corresponds in Fig. 2 a value of the tornado path width $b = \bar{b}$.

A final comment pertains to the case where the direction, α, of the tornado axis of translation is a random variable. In that case

$$P_A(T, V_{torn}) = \sum_i P_A(T, V_{torn}, \alpha_i) \tag{9}$$

where $P_A(T, V_{torn}, \alpha_i)$ = probability that point A will be struck by a tornado with maximum wind speed larger than V_{torn}, and with a translation axis having a direction defined by α_i.

4. PROBABILITIES OF OCCURRENCE OF MISSILE HIT SPEEDS

4.1 SIMPLIFIED ANALYSIS

For the purposes of this report, a simplified analysis is defined as one that is based upon the following assumptions:

1. The number, geometry, and location of the potential targets is specified.

2. A missile set-up (consisting of number and location of missiles, all the missiles having the same aerodynamic coefficient, area, and mass) is specified. The probability of occurrence of this set-up is assumed to be unity.

3. The coefficient k in Eq. 2 is specified.

4. Tornadoes with a specified maximum wind speed, V_{torn}, equal to the maximum wind speed of the Design Basis Tornado will occur in such a way that their axes of translation will cross, and be normal to, a specified segment with length b. The seqment b is divided into N_1 subsegments. The probability of occurrence of a tornado, T_i, whose axis of translation passes through the center of such a subsegment is $10^{-7}/N_1$ per year.

The effect of tornado T_i is to sweep a number of missiles and cause some of them to hit the targets with various horizontal speeds. Let the highest of these speeds be denoted by V_m^{max}. The probability of occurrence of at least one hit with speed V_m^{max} is then $10^{-7}/N_1$. If, of the N_1 tornadoes T_i

($i = 2, 3, \ldots N_1$), a number q will be associated with hitting missile speeds greater than V_m^{max}, the probability of occurrence of hits with speeds equal to or greater than V_m^{max} will be $10^{-7}\ q/N_1$

4.2 ANALYSIS IN WHICH VARIABILITIES OF ADDITIONAL FACTORS ARE CONSIDERED

The procedure for estimating missile speeds developed in this report can also take into account the variabilities of the following factors:

1. Missile set-ups. As previously indicated, it is possible to specify N_2 missile set-ups, denoted by S_{Mi}, ($i = 1, 2, \ldots N_2$), each set-up being associated with a probability of occurrence $P(S_{Mi})$. The sum of these probabilities is unity.

2. Tornado type. Each tornado type is characterized by a maximum tornado wind speed and by the corresponding wind field as defined in Ref. 1. Let each tornado type be identified by the symbol T_{V_i} ($i = 1, 2, \ldots N_3$).

Probabilities of occurrence of various tornado types, $P(T_{V_i})$, can be estimated as suggested in Appendix A1 or by using additional information given, e.g., in Ref. 2. Note that

$$\sum_{i=1}^{N_3} P(T_{V_i}) = 10^{-7}C \tag{10}$$

In Eq. 10, C = 1 if the maximum wind speed in the least intense of the i tornado types, $\min[V_{torn\ i}]$, is equal to the maximum wind speed of the Design Basis Tornado at the geographical location of concern, V_{torn}^{DBT}. If $\min[V_{torn\ i}] < V_{torn}^{DBT}$, then $C > 1$.

3. Direction of Tornado Axis of Translation. Let each translation axis direction be denoted by α_i. To each α_i ($i = 1, 2, \ldots N_4$), there corresponds a probability of occurrence $P(\alpha_i)$, the sum of these probabilities being unity.

The probabilities of occurrence of missile hit speeds when the variabilities of factors 1 through 3 above are taken into account are calculated in a manner similar to that indicated for the case of the simplified analysis, except that the probability of occurrence of the largest hitting missile speed, V_m^{max}, associated with a given missile set-up S_{M_j}, a given tornado type, T_{V_k}, a given direction of the axis of translation, α_ℓ, and a given portion of the axis of translation, L_i, is

$$P_{ijk\ell}(V_m^{max}) = P(L_i)P(S_{M_j})P(T_{V_k})P(\alpha_\ell) \tag{11}$$

where

$$P(L_i) = \frac{\overline{b}}{\Delta L} \qquad (12a)$$

$$= \frac{1}{N_i} \qquad (12b)$$

The total probability of occurrence of hitting missile speeds equal to or larger than V_m^{max} is

$$P(V_m^{max}) = \sum_{i=1}^{N_1} \sum_{j=1}^{N_L} \sum_{k=1}^{N_j} \sum_{\ell=1}^{N_4} P(L_i)P(S_{M_j})P(T_{V_k})P(\alpha_\ell) \qquad (13)$$

5. NUMERICAL EXAMPLES

Figure 3 shows the plan of a BWR (Boiling Water Reator) nuclear power plant in which the structures denoted by 1,2,4,8, and 12 (i.e., containment, auxiliary building, control building, Diesel generator building, and standby service water cooling tower and basin, respectively) are considered to be important to safety and, therefore must "be designed to withstand the effects of natural phenomena such as tornadoes without loss of capability to perform their safety functions" [3]. These structures have been redrawn schematically in figure 4 to conform to the computer program input format. In Figure 4 the targets are numbered from 1 through 9, and the areas (or "lots") where the potential missiles are located before the tornado landing are numbered from I through IV. The missiles at rest are assumed to be at ground level (elevation zero). Elevations of the top horizontal plane of the targets are also shown in Figure 4 (for example, for target 1 the elevation of the top plane is + 40m). All dimensions of Figure 4 are in meters.

5.1 SIMPLIFIED ANALYSES

A set of basic cases was defined, corresponding to the following assumptions:

1. The target consists of any of the buildings denoted by 1 through 9 in figure 4.

2. The positions of the areas (lots) where the missiles are located before the tornado landing are those shown in figure 4.

3. The number and locations of missiles within these areas are as follows:

-Lot I:	One row of two missiles (distance between missiles in x direction: 15m)
-Lot II:	Two rows of 15 missiles each (distance between rows in y direction: 12m; distance between missiles in x direction: 3m.
-Lot III:	One missile

-Lot IV: Twenty rows of 14 missiles each (distance between rows in y direction: 3m; distance between missiles in x direction: 11m).

4. The tornado axes of translation cross, and are normal to, a segment $O'B = \overline{b} = 150$ m (see figure 4). The segment $\overline{b}$ is divided into 15 equal subintervals.

5. The angle α between the tornado translation axis and the y axis (figure 4) is 22°.

Calculations corresponding to the basic case were carried out for various values of V_{torn} and of k, for five types of missiles:

I - automobile with properties assumed in Ref. 1
II - automobile with properties based on data suggested in Ref. 4
III - wood plank
IV - 12" pipe with properties assumed in Ref. 1
V - 12" pipe with properties based on data suggested in Ref. 5.

The drag coefficient, area, and mass of these missiles are given in Table 1.

In addition to calculations based on the assumptions just described and corresponding to the basic case, calculations were carried out with one or two of these assumptions modified, all other assumptions being unchanged. The modified assumptions were the following:

- The angle α is different from 22°
- The coordinates $x_{o''}$, $y_{o''}$ of point O" (defining the position of lot IV) are different from those given in figure 4.
- The number of missiles in lot IV is different from that previously given for the basic case. (The modified number of missiles is devoted by n, while the number of missiles given for the basic case is denoted by n_{typ})
- The target consists of building 9 only, rather than of any of the buildings 1 through 9 of figure 4.

The results of the calculations are given in Table 1 for three probability levels. Note that Table 1 is divided into subsections, each identified by a group of three symbols. The first symbol is a Roman numeral indicating the missile type (I through V); the second symbol is a lower case letter indicating the maximum tornado wind speed (a, for 360 mph; b, for 300 mph; c, for 240 mph; d, for 380 mph; and e, for 200 mph); the third symbol is an arabic numeral (1, for the basic case; 2, for the case in which lot IV is displaced; 3, for the case in which the number of missiles is changed; and 4, for the case where the target consists of building 9 only).

Note also that for certain parameter values, missile speeds corresponding to the probability 10^{-7}, and/or 0.5×10^{-7}, and/or 0.06×10^{-7} are not entered into Table 1 (see, for example, subsection Ia2 of Table 1 for $k = 0.9$, $x_{o''} = 60$ m, $y_{o''} = -200$m). This reflects the fact that at least one, eight, or fourteen respectively of the $N_1 = 15$ tornadoes hitting the site (each with probability $10^{-7}/15$) fail to hurl at least one missile onto the target.

5.2 COMMENTS ON RESULTS OF SIMPLIFIED ANALYSES

Effect of Parameter k. Note from subsection Ia1 of Table 1 that as k increases, the speeds corresponding to a given probability level increase. Indeed, if k were extremely small, the motion of the object would in general begin at a time when the distance between the object and the tornado center would still be relatively large, so that the object would in effect be swept away from the zone of strong tornado winds. Conversely, if k is relatively large, the object stays in its rest position until the tornado winds are sufficiently strong to hurl it with great force. The trend observed in subsections Ia1 is also evident in other subsections.

However, an increased k does not necessarily result in an increased hit speed (at some given probability level): see, for example, subsection IIId1 of Table 1). One explanation is that to an increased k there may correspond certain missile trajectories that do not result in a hit. Therefore, even though the speed of the missile at some point on its trajectory would increase if k were increased, this is irrelevant from the standpoint of this project as long as the missile with the higher speed would fail to hit a target. Another explanation for occasional decreases of the hit speed (for any given probability) as k increases is that, in certain cases, to a smaller value of k there could correspond more unfavorable initial conditions for some missiles.

Direction of Tornado Axis of Translation. For each type of missile, subsections of Table 1 identified by symbols ending in a1 and b1 include in parentheses and brackets speeds corresponding to the angles $\alpha = 1°$ and $\alpha = 45°$, respectively (as opposed to $\alpha = 22°$, which constitutes the basic case). It can be seen that, for the cases investigated, the tornado effects are generally less severe in this example for $\alpha = 1°$ and $\alpha = 45°$ than for $\alpha = 22°$.

Influence of Location of Lot IV. In this example, lot IV contains the bulk of the missiles present on the nuclear power plant grounds. It is seen that if the lot is at a relatively large distance from the targets ($y_o'' = -500$ m), the hit speeds are, as expected, lower than those corresponding to $y_o'' =$ 100 m in most, though not all cases.

Note that changing the position of lot IV from $x_o'' = 60$ m, $y_o'' = -100$ m to $x_o'' = 160$ m, $y_o'' = -200$ m, does not always result in a reduction of the hit speeds corresponding to a given probability. For example, such a reduction (from 43m/s to 13 m/s) does occur for hit speeds with 10^{-7} probability of occurrence in the case of missile I with k = 0.9 and $V_{torn} = 360$ mph (subsection Ia2 of Table 1). However, in the case of missile I with k = 0.9 and $V_{torn} = 240$ mph, there occurs an increase from 33m/s if $x_o'' = 60$ m, $y_o'' = -100$ m, to 43 m/s if $x_o'' = 160$m, $y_o'' = -200$ m.

Influence of Number of Missiles. The number of missiles in lot IV was reduced in the ratios $n/n_{typ} = 1/8$ and $n/n_{typ} \approx 1/50$. This was done by reducing the number of rows of missiles, and of missiles in each row, from 20 to 5, and 14 to 7, respectively, for $n/n_{typ} = 1/8$, and from 20 to 2, and 14 to 3 respectively, for $n/n_{typ} \approx 1/50$. For the case $n/n_{typ} = 1/8$ the effect of the reduction upon the missile speeds corresponding to a given probability of hit was generally small, although, in many instances, of the $N_1 = 15$ tornadoes assumed to hit the plant site (each having a probability of occurrence $10^{-7}/N_1$) at least one hurled no missile onto the targets when the number of missiles was reduced. For the case $n/n_{typ} \approx 1/50$ the effect of the reduction was, as expected more significant in most situations.

When the number of missiles in lot IV was increased by a factor of 4 (this was done in the case of the plank and of the 12" pipe), the resulting missile hit speeds were found not to differ, or not to differ significantly, from those obtained in the basic case.

Influence of Target Area. If the only target considered was building 9, as opposed to any of the buildings 1 through 9, the missile speeds corresponding to a given probability level were generally reduced with respect to those obtained for the basic case, although in a few cases the reductions were small.

5.3 COMPARISON BETWEEN VALUES OF HIT SPEEDS FOR THE BASIC CASE AND VALUES V_H^{max} OBTAINED IN REF. 1

It is recalled that the tornado paths assumed in Table 1 are defined by the position of the segment O'B of figure 4. It may well be that a different set of paths might in certain instances have resulted in more severe hits. It appears therefore reasonable to use for design purposes speeds corresponding in Table 1 to the probability level 0.5×10^{-7}, say, rather than exactly 10^{-7}.

Missile I ("NBS" Automobile), $V_{torn} = 360$ mph: $V_H^{max} = 59$ m/s (Ref. 1). It is seen from Table 1, subsections Ia1 through Ia4, that for $k \leq 0.9$, $V_m < 47$ m/s in all cases investigated. While it may be argued that the restraining force for an automobile would usually be of the order of magnitude of the friction force, i.e., $k = 0.3$, say, it is conceivable that some automobiles might experience some form of blockage that would raise k to higher values. However, if such blockage occurs, it might be expected that the number of automobiles affected by it would be small. Table Ia3 shows that if $n/n_{typ} \approx 1/50$ (i.e., if there are only about five automobiles in lot IV, then V_m corresponding to the probability 0.5×10^{-7} decreases both for $k = 0.9$ and $k = 2.0$ from 45 m/s and 64 m/s to 39 m/s and 17 m/s respectively.

Therefore, in view of the results of subsections Ia1 through Ia4 of Table 1, and assuming that very few automobiles have restraining forces with $k \geq 1.3$, it is reasonable to assume for design purposes that the speed of missile I is:

$$V_m \approx 50 \text{ m/s for } V_{torn} = 360 \text{ mph}$$

This is a less severe design criterion than that suggested in Ref. 1.

Missile I ("NBS" Automobile, V_{torn} = 300 mph: V_H^{max} = 52 m/s (Ref. 1)

A comparison between subsections Ia1 and Ib1 of Table 1 shows that the values of the hit speeds corresponding to a probability of occurrence 0.5×10^{-7} are about the same for V_{torn} = 300 mph as for V_{torn} = 360 mph, except in the case $k = 0.3$, when they are considerably larger for V_{torn} = 300 mph. This is a surprising result, which could be explained by noting that, for constant k, the missile will begin its motion from a position that is closer to the tornado zone of strongest winds when the oncoming tornado is weaker; such a position may in certain cases result in larger hit speeds.

A comparison between subsections Ib1 and Ia1 suggests that design hit speeds for missile I should be only marginally lower in the case V_{torn} = 300 mph than in the case V_{torn} = 360 mph. It is therefore suggested that for design purposes,

$V_m \approx 48$ m/s for V_{torn} = 300 mph

This value is somewhat lower than that suggested in Ref. 1.

Missile I ("NBS" Automobile), V_{torn} = 240 mph: V_H^{max} = 41 m/s (Ref. 1)

A comparison between subsections Ia1, Ib1 and Ic1 of Table 1, for both the 0.5×10^{-7} and the 10^{-7} probability levels, suggests that for design purposes it is reasonable to assume

$V_m \approx 45$ m/s for V_{torn} = 240 mph

This value is somewhat larger than that suggested in Ref. 1.

Subsections Id1 and Ie1 show values of V_m for V_{torn} = 380 mph and V_{torn} = 200 mph, respectively. The values for V_{torn} = 380 mph differ little from the corresponding values for V_{torn} = 360 mph. Note also that, for $k = 0.5$ and $k = 0.9$, values of V_m for the probability level 10^{-7} are, surprisingly, considerably higher for V_{torn} = 200 mph than the corresponding values for V_{torn} = 240 mph.

Missile II ("EPRI" Automobile), V_{torn} = 360 mph: V_H^{max} = 46 m/s (Ref. 1)

From a comparison of subsections IIa1 and Ia1 it is seen that, for the same values of k, speeds V_m are higher for Missile II ("EPRI" automobile) than for Missile I ("NBS" automobile). The explanation offered is similar to that advanced in connection with Missile I, V_{torn} = 300 mph. In this case Missile II will begin its motion from a position that is closer to the tornado zone of strongest winds than would Missile I (the coefficient k being the same), with a consequent increase in the value of V_m.

Therefore it appears reasonable to suggest for design purposes

$V_m = 55$ m/s for $V_{torn} = 360$ mph

i.e., a larger value than that suggested in Ref. 1.

Missile II ("EPRI" Automobile), $V_{torn} = 300$ mph: $V_H^{max} = 27$ m/s (Ref. 1)

A comparison between subsections IIb1 and IIa1 of Table 1 suggests that, for design purposes, the hit speed should be at least

$V_m = 50$ m/s for $V_{torn} = 300$ mph

This is considerably higher than the value suggested in Ref. 1.

Missile II ("EPRI" Automobile), $V_{torn} = 240$ mph: $V_H^{max} = 7$ m/s (Ref. 1)

From subsections IIc1, IIb1, and IIa1, it would follow that, for design purposes,

$V_m = 45$ m/s for $V_{torn} = 240$ mph

versus 7 m/s, as suggested in Ref. 1.

Missile III (Plank), $V_{torn} = 360$ mph: $V_H^{max} = 83$ m/s (Ref. 1)

Subsections IIIa1 through IIa4 of Table 1 suggest that, for design purposes, missile speeds need not exceed

$V_m = 60$ m/s for $V_{torn} = 360$ mph

i.e, about 20 m/s less than the value of Ref. 1. Note that the restraining force for a plank can be many times larger than the plank weight. This is a factor that was considered in selecting the speed suggested above.

Missile III (Plank), $V_{torn} = 300$ mph: $V_H^{max} = 70$ m/s (Ref. 1)

Subsections IIIb1 and IIIb2 of Table 1 suggest that, for design purposes, missile speeds need not exceed

$V_m = 55$ m/s for $V_{torn} = 300$ mph

i.e., 15 m/s less than suggested in Ref. 1.

Missile III (Plank), $V_{torn} = 240$ mph: $V_H^{max} = 58$ m/s (Ref. 1)

Subsections IIIc1 through IIIc3 of Table 1 suggest that, for design purposes, missile speeds need not exceed

$V_m = 50$ m/s for $V_{torn} = 240$ mph

i.e., 8 m/s less than suggested in Ref. 1.

Missile IV ("NBS 12" Pipe), V_{torn} = 360 mph: V_H^{max} = 47 m/s (Ref. 1)

Subsections IVa1 through IVa4 of Table 1 suggest that, for design purposes,

V_m = 65 m/s for V_{torn} = 360 mph

i.e., considerably more than suggested in Ref. 1. As in the case of the plank, the writers believe that, in the case of the pipe, the restraining force can be larger than the missile weight.

Missile IV ("NBS" 12" Pipe), V_{torn} = 300 mph: V_H^{max} = 28 m/s (Ref. 1)

Subsections IVb1 and IVb2 suggest that, for design purposes,

V_m = 60 m/s for V_{torn} = 360 mph

i.e., more than twice as high as suggested in Ref. 1.

Missile IV ("NBS" 12" Pipe), V_{torn} = 240 mph: V_H^{max} = 7 m/s (Ref. 1)

Subsections IVc1 through IVc3 of Table 1 suggest that for design purposes,

V_m = 50 m/s for V_{torn} = 240 m/s

i.e., more than seven times as high as suggeted in Ref. 1.

Missile V ("JFC-AES" 12" Pipe), V_{torn} = 360 mph: V_H^{max} = 38 m/s (Ref. 1)

Subsection Va1 of Table 1 suggests that, for design purposes,

V_m = 62 m/s for V_{torn} = 360 mph

This is close to the value obtained for missile IV

Missile V ("JFC-AES" 12" Pipe), V_{torn} = 300 mph: V_H^{max} = 15 m/s (Ref. 1)

Subsection Vb1 of Table 1 suggests that, for design purposes:

V_m = 52 m/s for V_{torn} = 300 mph

This is somewhat less than the value V_m = 60 m/s obtained for missile IV.

Missils V ("JFC-AES" 12" Pipe), V_{torn} = 240 mph: V_H^{max} = 7 m/s (Ref. 1)

Subsection Vc1 of Table 1 suggests that for design purposes:

V_m = 45 m/s for V_{torn} = 240 mph

i.e., about 10% less than for missile IV.

5.4 ANALYSIS IN WHICH ADDITIONAL VARIABILITIES ARE TAKEN INTO ACCOUNT

Calculations were also carried out for missile II (compact automobile) and $k = 0.3$, $k = 0.5$, and $k = 0.9$, using the assumptions 1 through 5 that define the basic case in the preceding simplified analyses. However, unlike the cases previously dealt with, it was not assumed that the site is swept by tornadoes with equal intensities V_{torn}. Rather, it was assumed that in Eq. 13 the number of tornado types is $k = 11$, and that the probabilities of occurrence at the site of tornado types T_{v_k} are as follows:

k	1	2	3	4	5	6	7	8	9	10	11
T_{v_k} (mph)	200	240	300	310	320	330	340	350	360	370	380
10^7 $P(T_{v_k})$ per year	100	20	1.6	1.4	1.2	1.1	1.0	0.8	0.50	0.25	0.20

Note that $\Sigma P(T_{v_k})$ for $k \geq 9$ (i.e., the probability of occurrence of tornadoes with maximum speeds equal to or larger than 360 mph) is approximately 10^{-7}. The probabilities $P(T_{v_k})$ were calculated from Appendix A1 for maximum tornado speeds equal to a larger than 310 mph, as follows:

$$P(T_{v_k}) = p(T, V_{torn})_{V_{torn} = V_k} \frac{V_{k+1} - V_{k-1}}{2}$$

For maximum tornado speeds less than 310 mph, the curve representing the percent probability of exceeding the value of any given wind speed, included in Ref. 2, was used as a guide.

The resulting missile speed hits V_m, and their calculated probabilities of occurrence, are given below:

Missile II ("EPRI" automobile)

$k = 0.3$	$V_m = 47$ m/s	$P(47) = 2.47 \times 10^{-7}$/year
	$V_m = 48$ m/s	$P(48) = 0.73 \times 10^{-7}$/year
	$V_m = 49$ m/s	$P(49) = 0$
$k = 0.5$	$V_m = 58$ m/s	$P(58) = 1.44 \times 10^{-7}$/year
	$V_m = 59$ m/s	$P(59) = 0.65 \times 10^{-7}$/year
	$V_m = 60$ m/s	$P(60) = 0$
$k = 0.9$	$V_m = 66$ m/s	$P(66) = 1.12 \times 10^{-7}$/year
	$V_m = 67$ m/s	$P(67) = 0.68 \times 10^{-7}$/year
	$V_m = 70$ m/s	$P(70) = 0$

It can be seen that the results differ relatively little for those corresponding to the probability level 0.5×10^{-7} in subsection IIa1 of Table 1 (V_{torn} = 360 mph), i.e., 48 m/s versus 44 m/s ($k = 0.3$), 59 m/s versus 58 m/s ($k = 0.5$), and 67 m/s versus 64 m/s ($k = 0.9$).

6. SUMMARY AND CONCLUSIONS

A procedure was developed for estimating speeds with which postulated missiles hit any given set of targets in a nuclear power plant or similar installation. Hit speeds corresponding to probabilities of occurrence of the order of 10^{-7} were calculated for a given nuclear power plant, under various assumptions concerning the magnitude of the force opposing missile take-off, direction of tornado axis of translation, number and initial location of missiles, and size of target area. One feature of the calculations that distinguishes them from those of Ref. 1 is that the missile motion does not start from an initial position postulated a priori. Rather, the initial position of the missile is determined by the condition that the aerodynamic force induced by the tornado wind field exceed a specified restraining force specified via a nondimensional parameter k. As explained in some detail in Section 4.2, the results no longer depend on the parameter C_DA/m alone, but on that parameter and on the parameter k.

The results of the calculations suggest that it is reasonable to use the following hit speeds, V_m, for design purposes, in lieu of the speeds given in Ref. 1:

Missile I ("NBS" automobile)

Region I (see Ref. 2): V_m = 50 m/s in lieu of 59 m/s
Region II: V_m = 48 m/s in lieu of 52 m/s
Region III: V_m = 45 m/s in lieu of 41 m/s

Missile II ("EPRI" automobile)

Region I: V_m = 55 m/s in lieu of 59 m/s
Region II: V_m = 50 m/s in lieu of 52 m/s
Region III: V_m = 45 m/s in lieu of 41 m/s

Missile III (plank)

Region I: V_m = 60 m/s in lieu of 83 m/s
Region II: V_m = 55 m/s in lieu of 70 m/s
Region III: V_m = 50 m/s in lieu of 58 m/s

Missile IV ("NBS" 12" pipe)

Region I: V_m = 65 m/s in lieu of 47 m/s
Region II: V_m = 60 m/s in lieu of 28 m/s
Region III: V_m = 50 m/s in lieu of 7 m/s

Missile V ("JFC-AES" 12" Pipe)

Region I: V_m = 62 m/s in lieu of 38 m/s
Region II: V_m = 52 m/s in lieu of 15 m/s
Region III: V_m = 45 m/s in lieu of 6 m/s

The design values suggested above are tentative and subject to three major qualifications. First, they are based upon climatological, meteorological and aerodynamic models that are uncertain. In the writers' opinion these uncertainties are extremely difficult, if not impossible, to quantify in the present state of the art. Second, the suggested values are based upon a single nuclear power plant basic set-up. Calculations carried out for a different set-up might yield somewhat different results. Third, although calculations were carried out assuming thousands of tornado hits sweeping hundreds of missiles each, these calculations have not been exhaustive even for the single basic plant set-up dealt with herein. This was due to the limited resources (approximately one half man year, including computer program development) available for this project.

In spite of these limitations, the writers believe that useful new insights into the tornado-borne missile speed problems have been obtained, and that an efficient and practical computational tool has been developed, that can be used for the purpose of further investigating individual power plants and of refining the design criteria suggested herein.

7. REFERENCES

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2. Technical Basis for Interim Regional Tornado Criteria, Wash-1300 (UC-11) U.S. Atomic Energy Commission, Office of Regulation, Washington, D.C., 1978.

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4. Wind Field and Trajectory Models for Tornado-Propelled Objects, EPRI NP-748, Electrical Power Research Institute, Palo Alto, Calif., May 1978.

5. Costello, J. F., and Stephenson, A. E., "Free Fall of Large Pipes", Journal of the Engineering Mechanics Div., ASCE, April 1978, pp. 477-480.

Table 1. Values of Horizontal Missile Speeds at Time of Hit, V_m, in Meters Per Second, Corresponding to Various Probabilities of Occurrence

I Automobile with $C_D = 2.0$, $A = 6.3m^2$, $m = 1810$ kg

Ia. V_{torn} = 360 mph (V_H^{max} per NBSIR 76-1050: 59 m/s)

Ia1. Basic Case[a]

	10^7 x Probability		
k	1.0	0.5	0.06
0.3	20 (20)	22 (23)	24 (24)
0.5	27	37	43
0.9	43	45	47
1.3	53 (45) [39]	54 (54) [55]	55 (56) [56]
2.0	62	64	65

[a] Numbers between parentheses correspond to tornado direction α = 1°
Numbers between brackets correspond to tornado direction α = 45°

Ia2. Influence of Location of Lot IV

		10^7 x Probability		
k	x_o", y_o"[a]	1.0	0.5	0.06
0.9	60, - 100	43	45	47
	60, - 200	-	39	47
	160, - 200	13	47	47
	60, - 500	-	39	43
2.0	60, - 100	62	64	65
	60, - 200	-	40	65
	160, - 200	63	64	65

[a] meters

Ia3. Influence of Number of Missiles

			10^7 x Probability		
k	n/n_{typ}	x_o", y_o"[a]	1.0	0.5	0.06
0.9	1	60, - 100	43	45	47
	1/8		-	43	47
	1/50		-	39	46
	1	60, - 200	-	39	47
	1/8		-	39	47
	1	160, - 200	13	47	47
	1/8		-	47	47
2.0	1	60, - 100	62	64	65
	1/8		-	63	64
	1/50		-	17	64
	1	60, - 200	-	40	65
	1/8		-	39	64
	1	160, - 200	63	64	65
	1/8		16	62	64

[a] meters

Ia4. Influence of Target Area[a]

	10^7 x Probability		
k	1.0	0.5	0.06
0.5	27 (27)	36 (37)	41 (43)
0.9	- (43)	41 (45)	45 (47)
1.3	- (53)	49 (54)	54 (54)
2.0	- (62)	58 (64)	64 (65)

[a] Numbers not between parentheses represent speeds of hits on building 9 only. Numbers between parentheses represent speeds of hits on any of the buildings 1 through 9.

Ib. V_{torn} = 300 mph (V_H^{max} per NBSIR 76-1050: 52 m/s)

Ib1. Basic Case, and Influence of Target Area[a]

	10^7 x Probability		
k	1.0	0.5	0.06
0.3	22	31	35
0.5	22 (22)	33 (33)	37 (37)
0.9	38 (38)	46 (41)	48 (47)
1.3	52 (-)	53 (47)	54 (54)
2.0	59 (-)	60 (55)	60 (60)

[a] Numbers not between parentheses represent speeds of hits on any of buildings 1 through 9.
Numbers between parentheses represent speeds of hits on building 9 only.

Ib2. Influence of Location of Lot IV

		10^7 x Probability		
k	x_o", y_o"[a]	1.0	0.5	0.06
0.9	60, - 100	38	46	48
	60, - 200	38	39	40

[a] meters

Ic. V_{torn} = 240 mph (V_H^{max} per NBSIR 76-1050: 41 m/s)

Ic1. Basic Case[a]

	10^7 x Probability		
k	1.0	0.5	0.06
0.3	22	26	31
0.5	16	33	34
0.9	33	44	46
1.3	47 (35) [-]	50 (50) [50]	41 (51) [52]
2.0	53	53	54

[a] Numbers between parentheses correspond to tornado direction α = 1°
Numbers between bracktes correspond to tornado direction α = 45°

Ic2. Influence of Location of Lot IV

		10^7 x Probability		
k	x_o", y_o"[a]	1.0	0.5	0.06
	60, - 100	33	44	46
	60, - 200	32	33	45
0.9	160, - 200	43	44	45
	60, - 200	32	33	33
	60, - 100	53	50	54
2.0	60, - 200	-	33	49
	160, - 200	-	21	35

[a] meters

Ic3. Influence of Number of Missiles

		10^7 x Probability		
k	n/n_{typ}	1.0	0.5	0.06
	1	33	44	46
0.9	1/8	33	44	46
	1/50	33	38	45
	1	53	53	54
2.0	1/8	47	55	54
	1/50	-	21	54

Idl. V_{torn} = 380 mph

Idl. Basic Case

	10^7 x Probability		
k	1.0	0.5	0.06
0.9	42	44	47
2.0	64	65	66

Iel. V_{torn} = 200 mph

Iel. Basic Case

	10^7 x Probability		
k	1.0	0.5	0.06
0.5	34	35	35
0.9	40	42	43
1.3	44	45	46
2.0	-	-	45

II Automobile with $C_D = 1.5$, $A = 3.8\ m^2$, m = 1810 kg

IIa. V_{torn} = 360 mph (V_H^{max} per NBSIR 76-1050: 46 m/s)

IIa1. Basic Case[a]

	10^7 x Probability		
k	1.0	0.5	0.06
0.3	-	44	48
0.5	27	58	60
0.9	55	64	69
1.3	62 (38) [39]	68 (63) [55]	71 (70) [56]
2.0	67	71	74

[a] Numbers between parentheses correspond to tornado direction α = 1°
Numbers between brackets correspond to tornado direction α = 45°

IIa2. Influence of Location of Lot IV

		10^7 x Probability		
k	x_o'', y_o'' [a]	1.0	0.5	0.06
0.9	60, - 100	55	64	69
	60, - 100	-	64	68
	160, - 200	64	65	68
	60, - 500	-	-	32
2.0	60, - 100	67	71	74
	60, - 200	-	74	75
	160, - 200	66	70	74

[a] meters

IIa3. Influence of Number of Missiles

k	n/n_{typ}	x_o", y_o"	10^7 x Probability 1.0	 0.5	 0.06
0.9	1	60, - 100	55	64	69
	1/8		54	63	66
	1/50		-	55	66
	1	60, - 200	-	64	68
	1/8		-	49	68
	1	160, - 200	64	66	68
	1/8		63	66	66
	1	60, - 500	-	-	32
	1/8		-	-	32
2.0	1	60, - 100	67	71	74
	1/8		57	71	74
	1/50		-	51	70
	1	60, - 200	-	74	75
	1/8		-	64	75
	1	160, - 200	66	70	74
	1/8		63	70	74

[a] meters

IIa4. Influence of Target Area[a]

k	10^7 x Probability 1.0	 0.5	 0.06
0.5	27 (27)	44 (58)	54 (60)
0.9	41 (55)	54 (64)	68 (69)
1.3	40 (62)	63 (68)	71 (71)
2.0	- (67)	67 (71)	74 (74)

[a] Numbers not between parentheses represent speeds of hits on building 9 only. Numbers between parentheses represent speeds of hits on any of the buildings 1 through 9.

IIb. V_{torn} = 300 mph (V_H^{max} per NBSIR 76-1050: 27 m/s)

IIb1. Basic Case, and Influence of Target Area[a]

	10^7 x Probability		
k	1.0	0.5	0.06
0.3	42	46	48
0.5	44 (-)	53 (45)	56 (54)
0.9	52 (30)	57 (57)	61 (61)
1.3	56 (-)	60 (60)	62 (62)
2.0	53 (-)	54 (55)	55 (56)

[a] Number not between parentheses represent speeds of hits on any of buildings 1 through 9.
Number between parentheses represent speeds of hits on buildings 9 only.

IIb2. Influence of Location of Lot IV

		10^7 x Probability		
k	x_o", y_o"[a]	1.0	0.5	0.06
0.9	60, - 100	52	57	61
	60, - 500	30	30	30

[a] meters

IIc. V_{torn} = 240 mph (V_m per NBSIR 76-1050: 7 m/s)

IIc1. Basic Case[a]

k	10^7 x Probability 1.0	 0.5	 0.06
0.3	35	42	46
0.5	40	46	49
0.9	46	47	51
1.3	45 (39) [30]	45 (55) [45]	45 (56) [46]
2.0	-	-	-

[a] Numbers between parentheses correspond to tornado direction α = 1°
Numbers between brackets correspond to tornado direction α - 45°

IIc2. Influence of Location of Lot IV

k	x_o", y_o"[a]	10^7 x Probability 1.0	 0.5	 0.06
0.9	60, - 100	46	47	52
	60, - 200	26	51	52
	160, - 200	26	51	52
	60, - 500	26	28	31
2.0	60, - 100	-	-	-
	60, - 200	-	-	-
	160, - 200	-	-	-

[a] meters

IIc3. Influence of Number of Missiles

k	n/n_{typ}	10^7 x Probability 1.0	 0.5	 0.06
0.9	1	46	47	51
	1/8	40	47	49
	1/50	26	40	48
2.0	1	-	-	-
	1/8	-	-	-
	1/50	-	-	-

IId. V_{torn} = 380 mph

IId1. Basic Case

	10^7 x Probability		
k	1.0	0.5	0.06
0.9	62	65	70
2.0	71	74	77

IIe. V_{torn} = 200 mph

IIda. Basic Case

	10^7 x Probability		
k	1.0	0.5	0.06
0.5	37	40	41
0.9	19	35	38
1.3	-	37	42
2.0	-	-	-

III Plank with $C_D = 2.0$, $A = 0.7\ m^2$, $m = 51.9$ kg

IIIa. $V_{torn} = 360$ mph (V_H^{max} per NBSIR 76-1050: 83 m/s)

IIIa1. Basic Case[a]

	10^7 x Probability		
k	1.0	0.5	0.06
0.3	26	27	29
0.5	40	54	63
0.9	40	55	62
1.3	40 (-) [28]	55 (50) [53]	62 (58) [60]
2.0	31	55	62
5.0	34 (-) [28]	55 (-) [53]	62 (58) [60]

[a] Numbers between parentheses correspond to tornado direction $\alpha = 1°$
Numbers between bracket correspond to tornado direction α 45°

IIIa2. Influence of Location of Lot IV

		10^7 x Probability		
k	x_o", y_o"[a]	1.0	0.5	0.06
0.9	60, - 100	40	55	62
	60, - 200	38	55	62
	160, - 200	40	53	61
	60, - 500	21	55	61
2.0	60, - 100	31	55	62
	60, - 200	40	61	62
	160, - 200	32	55	62
5.0	60, - 100	34	55	62
	60, - 200	33	55	62
	160, - 200	34	55	62

[a] meters

IIIa3. Influence of Numbers of Missiles

			10^7 x Probability		
k	n/n_{typ}	x_o", y_o"[a]	1.0	0.5	0.06
0.9	1	60, - 100	40	55	62
	4		40	55	62
	1/8		40	55	61
	1/50		40	55	61
	1	60, - 200	38	55	62
	1/8		38	55	62
	1	160, - 200	40	53	61
	1/8		37	53	61
2.0	1	60, - 100	31	55	62
	4		31	55	62
	1/8		31	53	62
	1/50		31	53	62
	1	60, - 200	40	61	62
	1/8		40	60	62
	1	160, - 200	32	55	62
	1/8		32	55	62
5.0	1	60, - 100	34	55	62
	4		34	55	61
	1/8		34	54	61
	1/50		34	53	61
	1	60, - 200	33	55	62
	1/8		33	55	62
	1	160, - 200	34	55	62
	1/8		34	55	62

[a] meters

IIIa4. Influence of Target Area[a]

k	10^7 x Probability		
	1.0	0.5	0.06
0.9	- (40)	50 (55)	58 (62)
2.0	30 (31)	50 (55)	57 (62)
5.0	- (34)	49 (55)	57 (62)

[a] Numbers not between parentheses represent speeds of hits on building 9 only. Numbers between parentheses represent speeds of hits on any of the buildings 1 through 9.

IIIb. V_{torn} = 300 mph (V_H^{max} per NBSIR 76-1050: 70 m/s)

IIIba. Basic Case, and Influences of Target Area[a]

k	10^7 x Probability		
	1.0	0.5	0.06
0.3	22	23	25
0.5	35	50	58
0.9	20 (-)	52 (50)	58 (58)
1.3	25	52	58
2.0	38 (33)	52 (50)	58 (57)
5.0	- (-)	52 (49)	58 (57)

[a] Numbers not between parentheses represent speeds of hits on any of buildings 1 through 9.
Numbers between parentheses represent speeds of hits a building 9 only.

IIIb2. Influence of Location of Lot IV

k	x_o", y_o"[a]	10^7 x Probability		
		1.0	0.5	0.06
0.9	60, - 100	20	52	58
	60, - 500	20	52	57

[a] meters

IIIc. V_{torn} = 240 mph (V_H^{max} per NBSIR 76-1050: 58 m/s)

IIIc1. Basic Case[a]

	10^7 x Probability		
k	1.0	0.5	0.06
0.3	19	20	21
0.5	16	45	50
0.9	30	46	50
1.3	32 (33) [33]	47 (38) [49]	50 (50) [51]
2.0	35	47	50
5.0	- (-) [45]	47 (-) [49]	50 (49) [53]

[a] Numbers between parentheses correspond to tornado direction α = 1°
Numbers between brackets correspond to tornado direction α = 45°

IIIc2. Influence of Location of Lot IV

		10^7 x Probability		
k	x_o", y_o"[a]	1.0	0.5	0.06
0.9	60, - 100	30	46	50
	60, - 200	29	46	50
	160, - 200	31	46	50
	60, - 500	38	47	50
2.0	60, - 100	35	47	50
	60, - 200	-	47	50
	160, - 200	-	47	50
5.0	60, - 100	-	47	50
	60, - 200	-	47	50
	160, - 200	-	47	51

[a] meters

IIIc3. Influence of Number of Missiles

		10^7 x Probability		
k	n/n_{typ}	1.0	0.5	0.06
0.9	1	30	46	50
	4	32	47	51
	1/8	30	46	50
	1/50	-	46	50
2.0	1	35	47	50
	4	35	47	50
	1/8	-	46	50
	1/50	-	46	50
5.0	1	-	47	50
	4	-	47	50
	1/8	-	46	50
	1/50	-	46	50

IIId. V_{torn} = 380 mph

IIId1. Basic Case

	10^7 x Probability		
k	1.0	0.5	0.06
0.9	43	53	62
2.0	37	54	63
5.0	30	54	63

IIIe. V_{torn} = 380 mph

IIIe1. Basic Case

	10^7 x Probability		
k	1.0	0.5	0.06
0.5	28	38	45
0.9	27	39	45
1.3	28	39	45
2.0	32	42	45
5.0	-	42	45

IV 12" Pipe with $C_D = 0.7$, $A = 1.6\ m^2$, $m = 341$ kg

IVa. $V_{torn} = 360$ mph (V_H^{max} per NBSIR 76-1050: 47 m/s)

IVa1. Basic Case[a]

	10^7 x Probability		
k	1.0	0.5	0.06
0.3	-	36	45
0.5	29	57	59
0.9	55	64	68
1.3	61 (40) [36]	68 (63) [70]	71 (71) [71]
2.0	70	73	75

[a] Number between parentheses correspond to tornado direction $\alpha = 1°$
Number between brackets correspond to tornado direction $\alpha = 45°$

IVa2. Influence of Location of Lot IV

		10^7 x Probability		
k	x_o", y_o"[a]	1.0	0.5	0.06
0.9	60, - 100	55	64	68
	60, - 200	-	65	67
	160, - 200	-	66	67
	60, - 500	-	-	30
2.0	60, - 100	-	68	71
	60, - 200	-	71	73
	160, - 200	-	-	73

[a] meters

IVa3. Influence of Number of Missiles

			10^7 x Probability		
k	n/n_{typ}	x_o'', y_o''[a]	1.0	0.5	0.06
0.9	1	60, - 100	55	64	68
	4		58	66	68
	1/4		-	61	67
	1/16		-	52	67
	1	60, - 200	-	65	67
	1/4		-	41	66
	1	160, - 200	-	66	67
	1/4		-	65	67
2.0	1	60, - 100	70	73	75
	4		70	73	75
	1/4		56	69	74
	1/16		-	62	69
	1	60, - 200	-	71	73
	1/4		-	71	71
	1	160, - 200	-	-	73
	1/4		70	71	72

[a] meters

IVa4. Influence of Target Area[a]

	10^7 x Probability		
k	1.0	0.5	0.06
0.9	- (55)	54 (64)	61 (68)
2.0	61 (70)	62 (73)	62 (75)

[a] Numbers not between parentheses represent speeds of hits on building 9 only. Numbers between parentheses represent speeds of hits on any of the buildings 1 through 9.

IVb. V_{torn} = 300 mph (V_H^{max} per NBSIR 76-1050: 28 m/s)

IVb1. Basic Case, and Influence of Target Area[a]

	10^7 x Probability		
k	1.0	0.5	0.06
0.3	-	45	47
0.5	27	53	56
0.9	52 (-)	57 (54)	59 (61)
1.3	58	60	62
2.0	62 (61)	62 (62)	62 (62)

[a] Numbers not between parentheses represent speeds of hits on any of buildings 1 through 9.
Numbers in parentheses represent speeds of hits on building 9 only.

IVb2. Influence of Location of Lot IV

		10^7 x Probability		
k	x_o", y_o"[a]	1.0	0.5	0.06
0.9	60, - 100	52	57	59
	60, - 500	-	-	30

[a] meters

IVc. V_{torn} = 240 mph (V_H^{max} per NBSIR 76-1050: 7 m/s)

IVc1. Basic Case[a]

	10^7 x Probability		
k	1.0	0.5	0.06
0.3	23	26	31
0.5	39	45	49
0.9	45	47	52
1.3	52 (26) [50]	52 (52) [52]	53 (52) [53]
2.0	-	-	-

[a] Numbers between parentheses correspond to tornado direction α = 1°.
Numbers between brackets correspond to tornado direction α = 45°.

IVc2. Influence of Location of Lot IV

k	x_o'', y_o''[a]	10^7 x Probability		
		1.0	0.5	0.06
0.9	60, - 100	45	47	52
	60, - 200	26	47	51
	160, - 200	26	47	51
	60, - 500	26	28	30
2.0	60, - 100	52	52	53
	60, - 200	-	-	-
	160, - 200	-	-	-

[a] meters

IVc3. Influence of Number of Missiles

k	n/n_{typ}	10^7 x Probability		
		1.0	0.5	0.06
0.9	1	45	47	52
	4	46	50	52
	1/8	39	47	51
	1/50	26	40	47
2.0	1	-	-	-
	4	-	-	-
	1/8	-	-	-
	1/50	-	-	-

IVd1. V_{torn} = 380 mph

Id1. Basic Case

k	10^7 x Probability		
	1.0	0.5	0.06
0.9	-	65	69
2.0	-	74	77

IVe1. V_{torn} = 200 mph

Ie1. Basic Case

	10^7 x Probability		
k	1.0	0.5	0.06
0.5	34	35	35
0.9	40	42	43
1.3	44	45	46
2.0	-	-	45

V. 12" Pipe with C_D = 0.7, A = 1.16 m^2, m = 341 kg

Va. V_{torn} = 360 mph (V_H^{max} per NBSIR 76-050: 38 m/s)

Va1. Basic Case[a]

	10^7 x Probability		
k	1.0	0.5	0.06
0.3	-	53	57
0.9	55(-)	62 (55)	67 (64)
2.0	-	65	67

[a] Numbers in parentheses represent speeds corresponding to n/n_{typ} = 1/50

Vb. V_{torn} = 300 mph (V_H^{max} per NBSIR 76-1050 = 15 m/s)

Vb1. Basic Case[a]

10^7 x Probability

k	1.0	0.5	0.06
0.3	37	47	51
0.9	-(-)	52(-)	57(57)
2.0	-	-	43

[a] Numbers in parentheses represent speeds corresponding to n/n_{typ} = 1/50

Vc. V_{torn} = 240 mph (V_H^{max} per NBSIR 76-1050 = 6 m/s

Vc1. Basic Case[a]

10^7 x Probability

k	1.0	0.5	0.06
0.3	34	41	44
0.9	20(-)	45(34)	46(46)
2.0	-	-	-

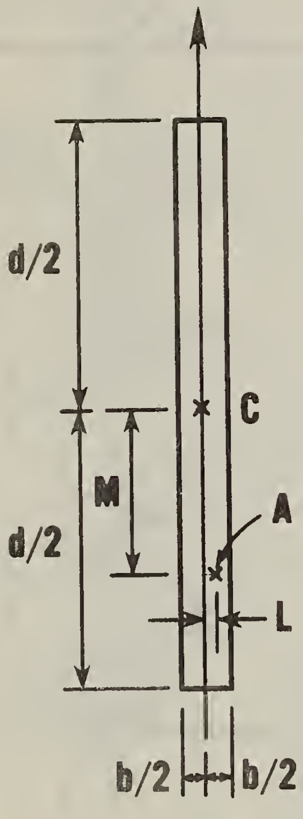

Figure 1

Schematic Representation of
a Tornado Path

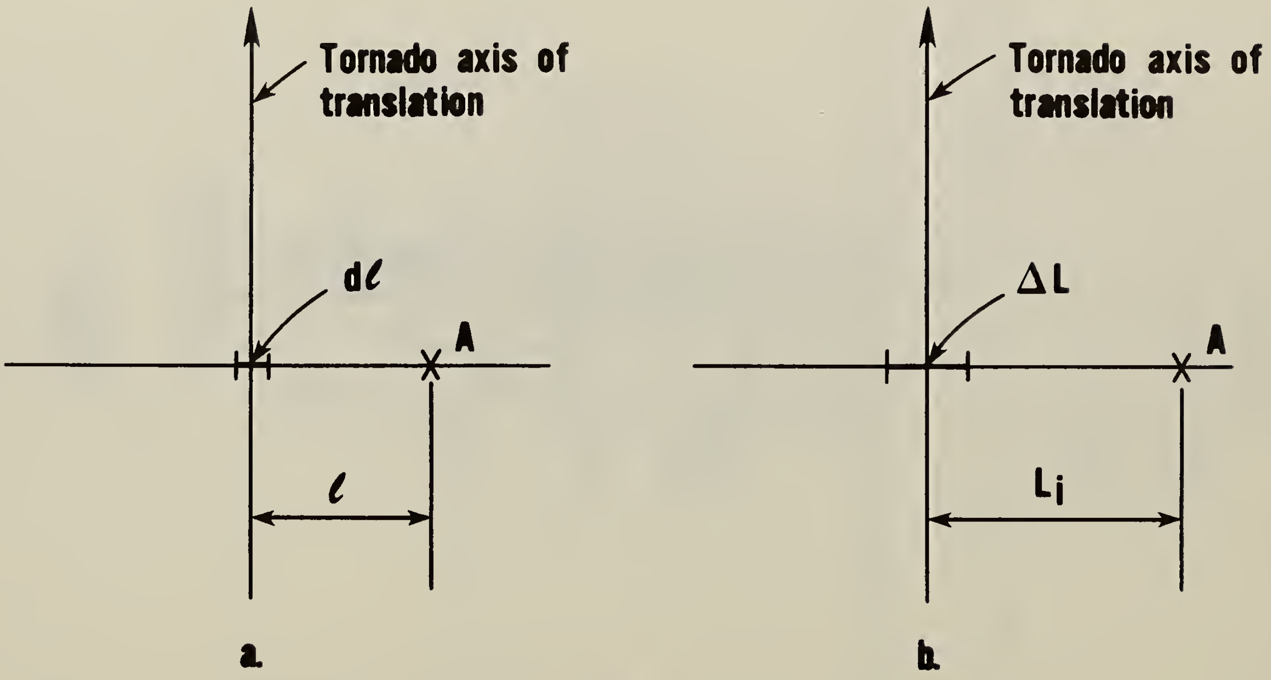

Figure 2

Notations

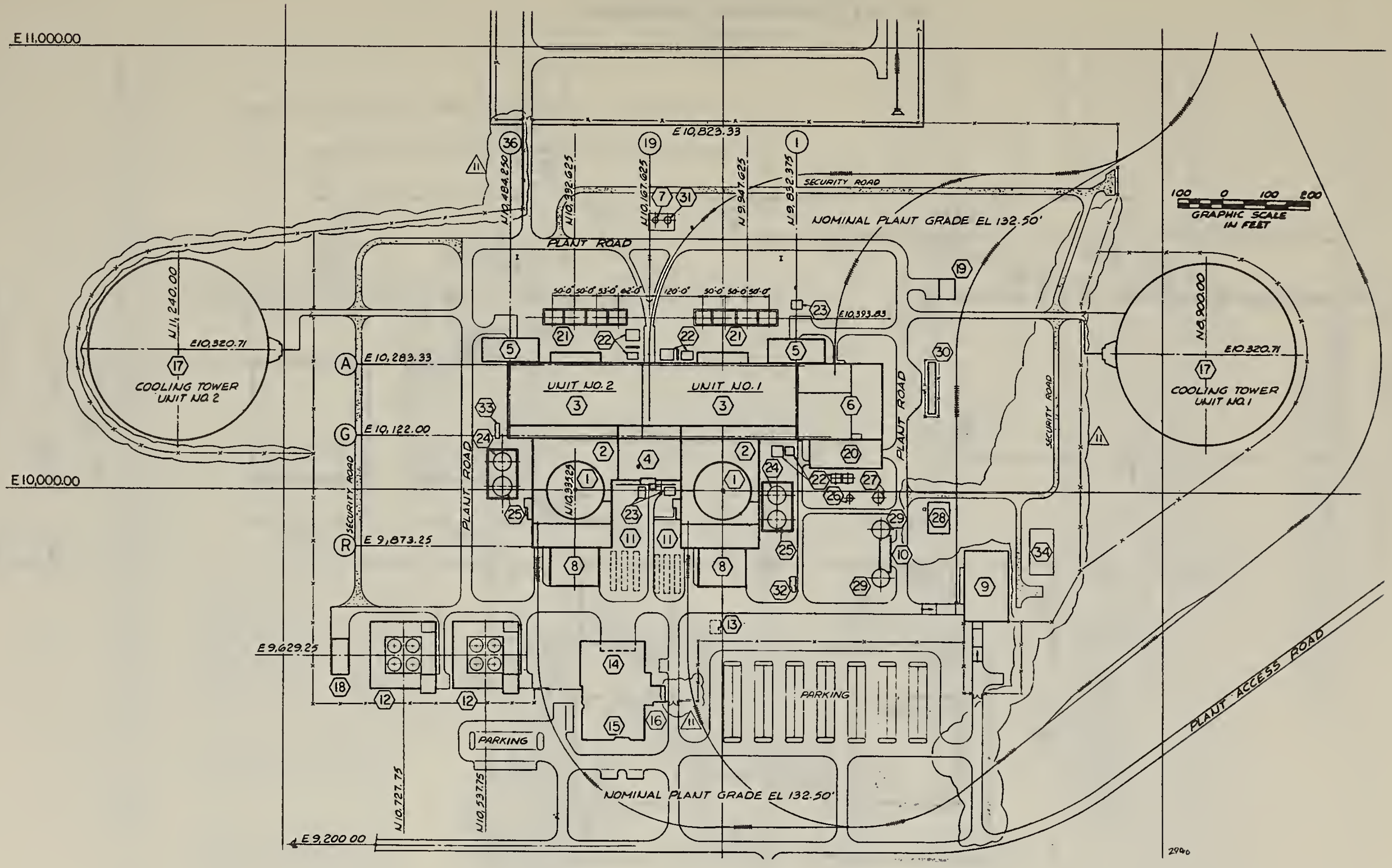

Figure 3
Plan View of Nuclear Power Plant
(Courtesy of Don Mehta, Bechtel
Corporation, Gaithersburg)

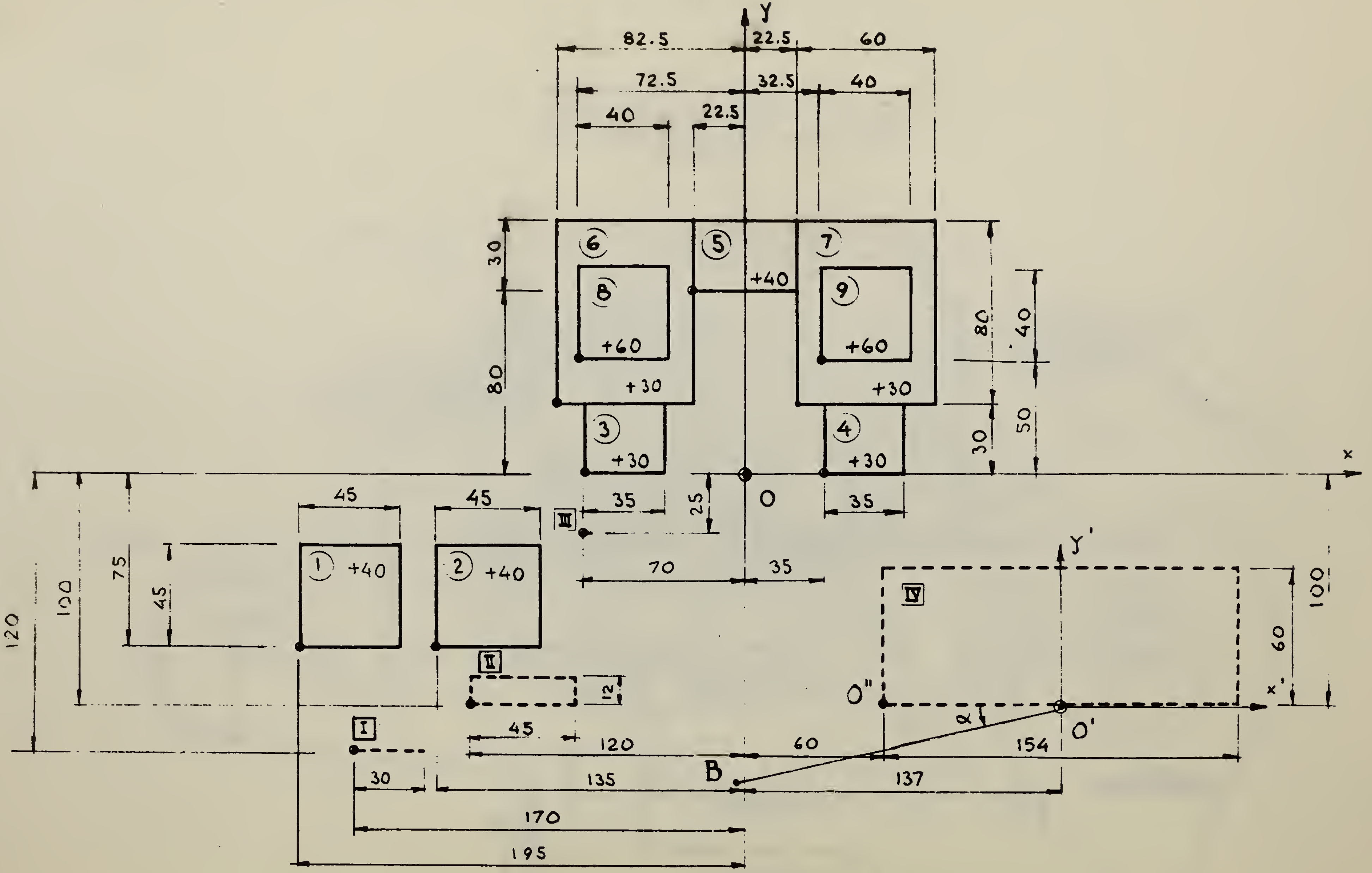

Figure 4
Schematic Representation of
Nuclear Power Plant

APPENDIX A1

PROBABILITY DENSITY FUNCTIONS OF MAXIMUM TORNADO WIND SPEED

In this Appendix an approximate representation, consistent with the assumptions implicit in Ref. 2, will be given for the probability density function of the maximum tornado wind speed V_{torn} at a location where the probability, $P(T, V_{torn})$, that a tornado with speed $V_{torn} \geq 360$ mph will occur is 10^{-7}/year. Let $P(T)$ and $P(V_{torn})$ denote the probability that a tornado will hit the location in question, and the probability that the maximum wind in a tornado is higher than V_{torn}, respectively. Then

$$P(T, V_{torn}) = P(T)\, P(V_{torn}) \tag{A1}$$

From Figs. A1 and A2 if follows that, in the regions where, nominally, $P(T, V_{torn}) = 10^{-7}$/year, the following approximate probabilities $P(T)$ and $P(V_{torn})$ are assumed in Ref. 2:

V_{torn} (mph)	$P(T)$	$P(V_{torn}) = 10^{-7}/P(T)$
380	190×10^{-5}	$1/(190 \times 10^{2})$
370	130×10^{-5}	$1/(130 \times 10^{2})$
360	105×10^{-5}	$1/(105 \times 10^{2})$
350	70×10^{-5}	$1/(70 \times 10^{2})$
340	45×10^{-5}	$1(45 \times 10^{2})$
330	33×10^{-5}	$1(33 \times 10^{2})$
320	23×10^{-5}	$1(23 \times 10^{2})$
310	16×10^{-5}	$1/(16 \times 10^{2})$

Since, in Ref. 2, $P(V_{torn})$ is assumed to be independent of geographical location, it follows from Eq. A1 that, at a location where $P(T, 360) = 10^{-7}$, $P(T, V_{torn}) = 105 \times 10^{-5}\, P(V_o)$. For various values of V_o, $P(T, V_{torn})$ will than have the values tabulated below

V_{torn} (mph)	$P(T, V_{torn})$
380	$(105/190)\ 10^{-7} \sim 0.55 \times 10^{-7}$
370	$(105/130)\ 10^{-7} \sim 0.80 \times 10^{-7}$
360	$10^{-7} = 1.00 \times 10^{-7}$
350	$(105/70)\ 10^{-7} \sim 1.50 \times 10^{-7}$
340	$(105/45)\ 10^{-7} \sim 2.33 \times 10^{-7}$
330	$(105/33)\ 10^{-7} \sim 3.30 \times 10^{-7}$
320	$(105/23)\ 10^{-7} \sim 4.50 \times 10^{-7}$
310	$(105/16)\ 10^{-7} \sim 6.00 \times 10^{-7}$

Remembering that $P(T, V_{torn}) = 1 - P_{cum}\,(T, V_o)$, where $P_{cum}\,(T, V_{torn})$ = cumulative distribution function of hit with speed V_{torn} (i.e., probability that a hit with maximum less than speed V_{torn} will occur), it follows that the tail of the probability density function $p(T, V_{torn})$ corresponding to $P_{cum}(T, V_{torn})$ may be represented approximately as in Fig. A3.

Similar calculations can be made for regions where $P(T, V_{torn}) = 10^{-7}$ for $V_{torn} = 300$ mph and $V_{torn} = 240$ mph.

Note that the calculations presented in this Appendix are merely illustrative. Indeed, values of P(T) and $P(V_{torn})$ somewhat different from those of Ref. 2 may be assumed, as indicated, e.g., in Ref. A1.

REFERENCE

A1. Abbey, R. F., "Risk Probabilities Associated With Tornado Windspeeds", in Proceedings, Symposium on Tornadoes, Texas Tech. University, Lubbock, TX, June 1976.

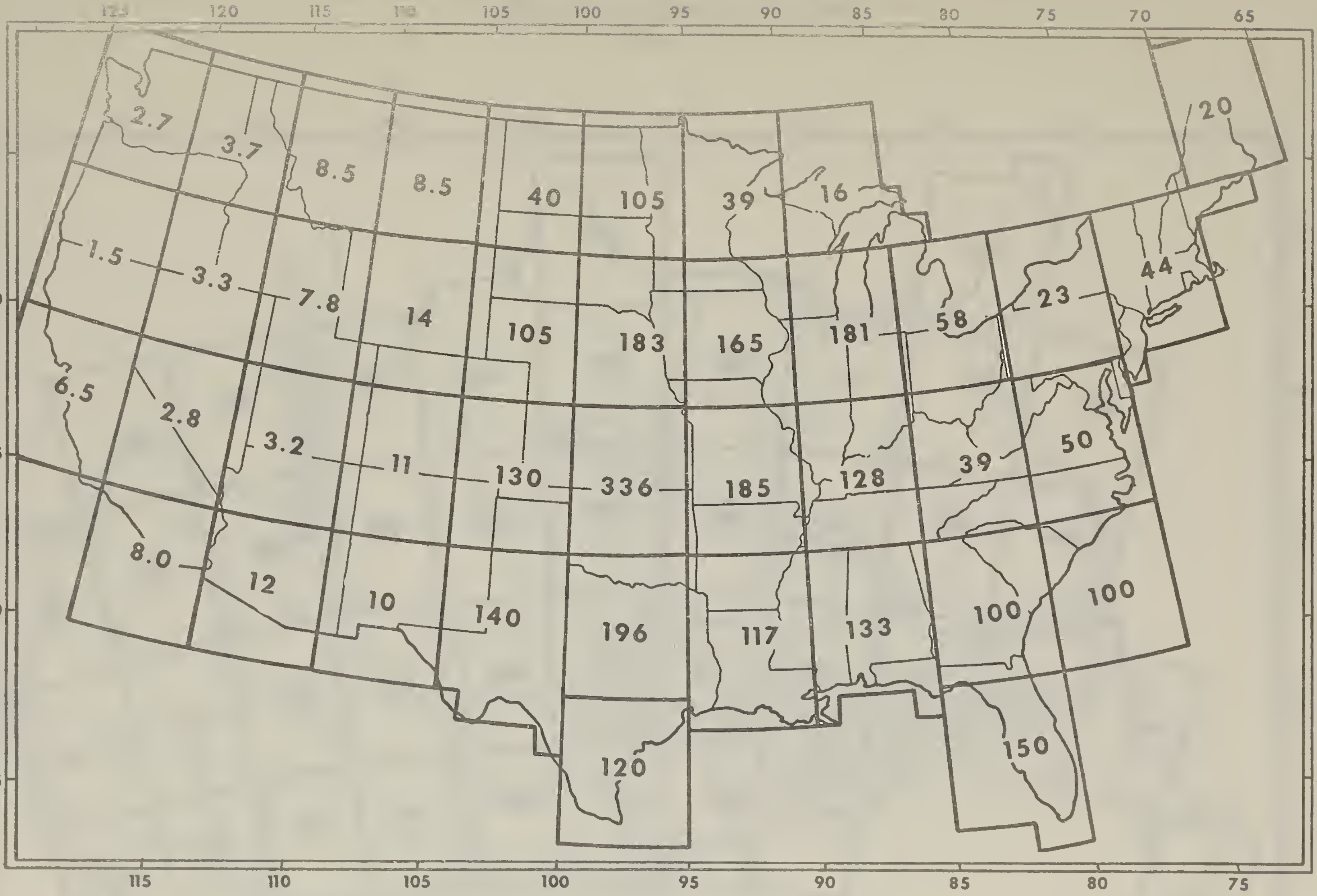

Figure A1
Tornado Strike Probability Within
Five-Degree Squares in the
Contiguous United States (Ref. 2)

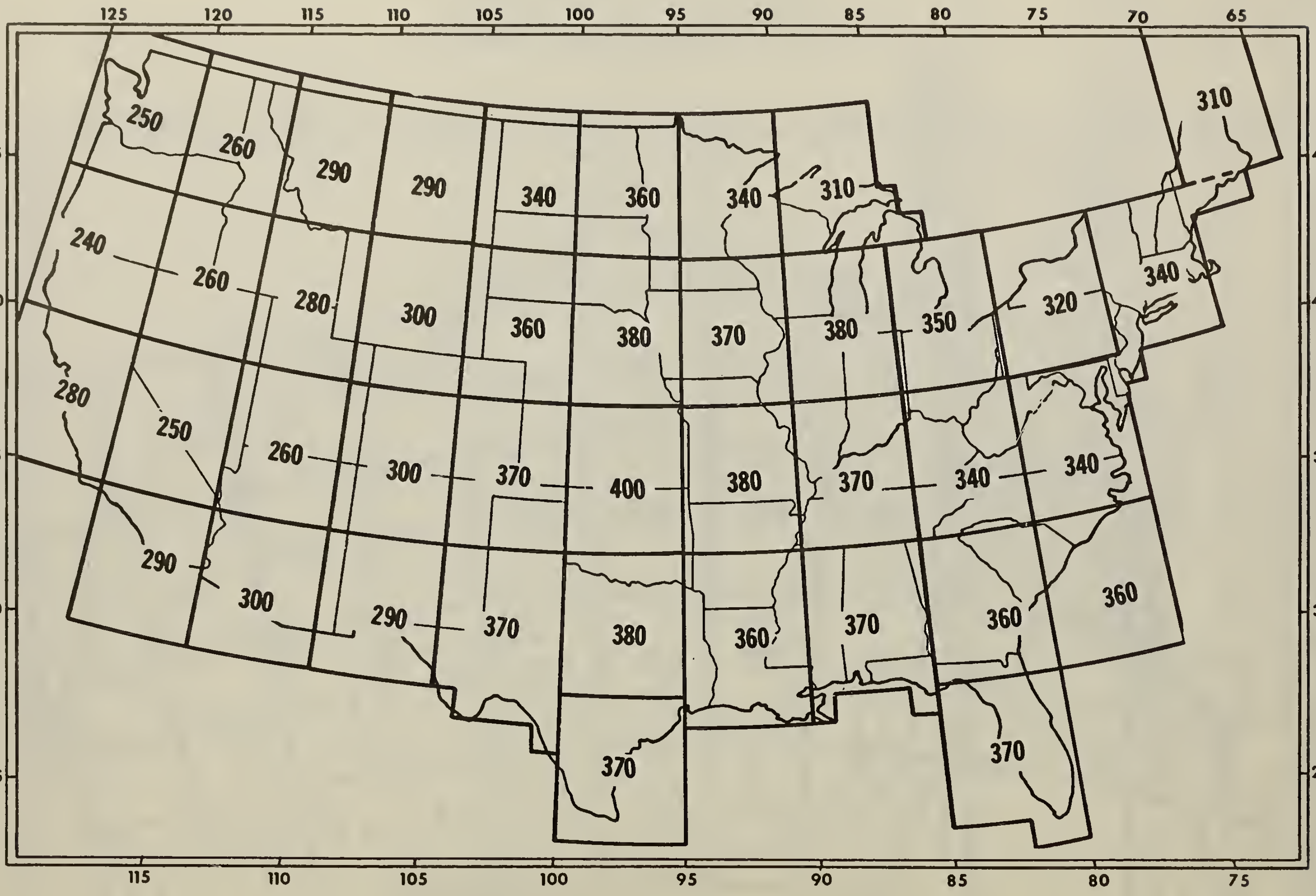

Figure A2
Calculated Tornado Wind Speed
by Five-Degree Squares for 10^{-7}
Probability per Year (Ref. 2)

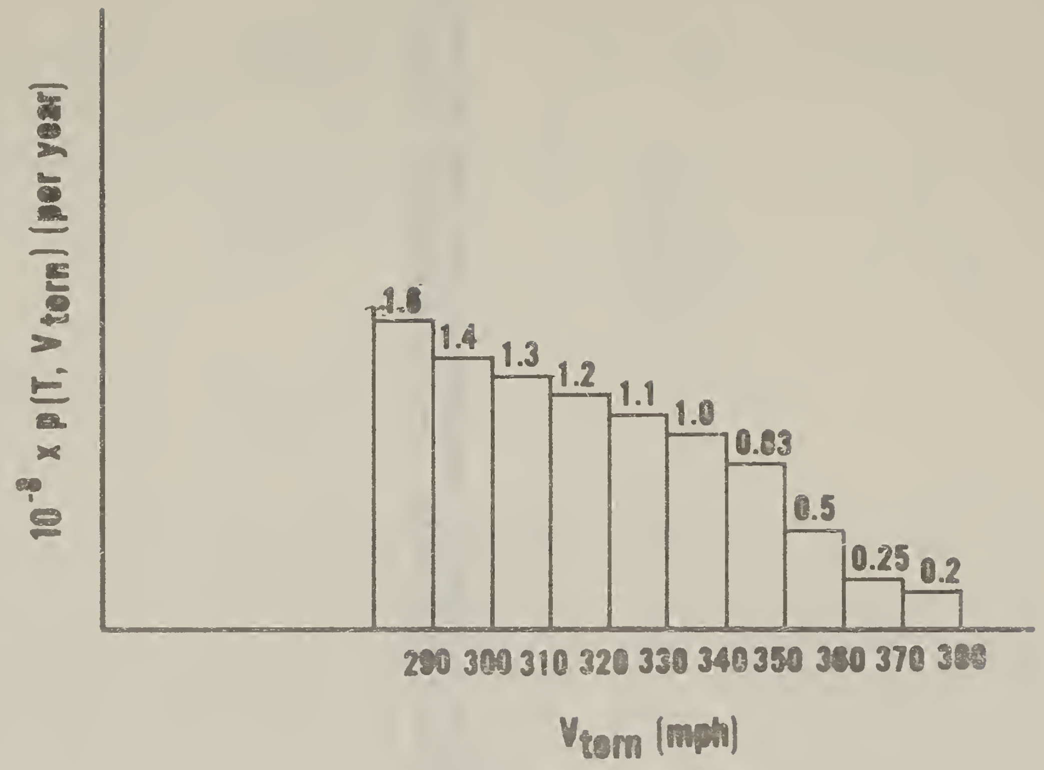

Fig. A3

Estimated Probability Density
Function of Tornado Wind Speeds

APPENDIX A2

COMPUTER PROGRAM: PARTIAL LISTING, AND SAMPLE INPUT AND OUTPUT

NOTE: Computer program is available on tape from the National Technical Information Service, Springfield, Virginia, 22151

Description of Input Data for Stage 1 Program

Group	Module	Type	Variable Name(s)	Format	Description
1	MAIN	Integer	PLEVEL	I2	Determines the amount of output to the printer. Note: Each group of output starts with a preface of the form (P<Level> - <Module>) Here, <Level> is the minimum value that PLEVEL must have in order for that particular output to occur. <Module> is the name of the module where the printing is done. -2 ≤ No output (except for warnings and fatal errors). -1 = Tornado landing distances and widths, number of hits, and hit counts by surface and face. 0 = (more than -1) Good level of descriptive output about the input. 1 = (more than 0) Short summary of each basis trajectory, summary of each hit. 2 = (more than 1) Summary of each event. 3 = (more than 2) Long summary of each basis trajectory. 4 ≥ (more than 3) Full output of each basis trajectory.
2	PRBDEF	Integer	JPN, JSA, JHS, JMT, IIAM, ITT, IAD, ITD, IBM	9I3	Problem definition indices. Note: These values do not affect the operation of the program. They may be used for documentation purposes. JPN = Problem number. JSA = Site number. JHS = Hit surface distribution number. JMT = Missile type number. IIAM = Distribution number of missile sets. ITT = Tornado type distribution number. IAD = Angle of tornado direction distribution number. ITD = Translation axes distribution number. IBM = Basis distribution number.
3	SITE	Real	DELYTN	F8.0	DELYTN = Distance between y translation lines in meters. (Note: y translation lines are parallel to the $O_M x_1$, axis of the $O_M x_1 y_1 z_1$, coordinate system defined below. They are used internally to locate efficiently regions where missile trajectories may intersect targets.)
		Real	XC, YC, ZC, LX, LY, LZ	6F8.0	XC,YC,LC = Coordinates of the point O_M (in meters) respect to the origin O of the reference Oxyz coordinate system. O_M is the center of the rectangular region that includes all the potential missiles at their initial positions. The system Oxyz is chosen arbitrarily for convenience. LX,LY,LZ = Length of the sides parallel to the $O_M x_1$, $O_M y_1$, $O_M z_1$ axes (in meters) respectively of the parallelepiped containing all the potential missiles at their initial positions. $O_M x_1$, $O_M y_1$, $O_M z_1$ are parallel to Ox, Oy, Oz, respectively.

Description of Input Data for Stage 1 Program

Group	Module	Type	Variable Name(s)	Format	Description
4	HITSRF	Integer	NHR	I3	NHR = number of hit regions [for example, Figure 4 of the report contains 9 hit regions numbered 1 through 9]. For each hit region:
		Real	$[XCR, YCR, ZCR, THETDX, LX, LY, LZ]_1^{NHR}$	[7F8.0]*	XCR, YCR, ZCR = coordinates with respect to point 0 (in meters) of one of the 4 corners of the rectangular base of the hit region. It is always assumed that this base is in a horizontal plane. The 3 lines that form the corner are denoted by 0_cx_2, 0_cy_2, 0_cz_2. 0_cz_2 is parallel to the axis 0_z of the reference system Oxyz. The coordinate system $0_cx_2y_2z_2$ must be right handed. THETDX = Counterclockwise angle (in degrees) by which the vector 0_x must be rotated in order to be parallel to and have the same direction as the vector 0_cx_2. LX,LY,LZ = Lengths (in meters) of the sides of the hit region (hit regions are always assumed to be parallelepipeds).
5	MSLTYP	Real	CDRAG, AREA, MASS, RFC	4F8.0	Missile description. CDRAG = Drag coefficient (nondimensional). AREA = Effective area (in meters^2). MASS = Mass (in kilograms). RFC = Horizontal restraining force factor (nondimensional) [RFC is denoted by k in the text, see Eq. 2 of the report].
6	AMDDEF	Integer	NIAM	I3	NIAM = the number of missile set-ups [denoted by N_2 in the report].
		Integer Integer	$\left[\begin{array}{l} I, NC(I) \\ [NX, NY, NZ]_1^{NC(I)} \end{array}\right]_1^{NIAM}$	I3,I6 [3I3]	Note: The I-th missile set-up is a union of NC(I) component lattices. Each component lattice has NX*NY*NZ missiles where NX, NY, and NZ may be different for each lattice [for example, in Figure 4 of the report there are NC(I) = 4 component lattices, denoted by I, II, III, IV].
		Real	$[PTT(I)]_1^{NTT}$	[5E12.5]	PAM(I) = The probability of occurrence of the I-th missile set-up [denoted by $P(S_{M_i})$ in the report].
7	TTDEF	Real, Integer	LUSER, RMXRTS, NTT	2F8.0, I3	LUSER = Distance (in meters) between tornado touchdown point and first line of potential missiles. This is used in the program only if RFC is so small that potential missiles would be swept off the ground even if tornado were at a very large distance from the site. (Recall that the theoretical wind speed at the site is equal to the tornado translation velocity, even if the tornado is at an infinite distance from the site.) RMXRTS = Radius of maximum wind velocity (in meters). NTT = Number of tornado types [Denoted by N_3 in the report]. SOEV(I) = Maximum wind velocity for the I-th tornado type (in miles/hour) [Denoted by V_{torn_i} in the report].
		Real	$[SOEV(I)]_1^{NTT}$	[10F8.0]	
		Real	$[PTT(I)]_1^{NTT}$	[5E12.5]	

* [. . .] = means that this format is used repeatedly.

Description of Input Data for Stage 1 Program

Group	Module	Type	Variable Name(s)	Format	Description
7	TTDEF				PTT(I) = Probability of occurrence of the I-th tornado type, divided by 10^{-7} [denoted in the report by $P(T_{V_i})/10^{-7}$].
8	ATDEF	Integer	NAD	I3	NAD = Number of directions of tornado axis of translation [denoted in the report by N_4].
		Real	$[AD(I)]_1^{NAD}$	[10F8.0]*	AD(I) = The angle (in degrees) defining the I-th direction of the tornado axis of translation [this angle is denoted in the report by α_i]. AD(I) are the counterclockwise angles [denoted in report by α_i] by which the vector Oy must be rotated in order to be parallel to and have the same direction as the tornado translation velocity vector.
		Real	$[PAD(I)]_1^{NAD}$	[5E12.5]	PAD(I) = Probability of occurrence of the I-th angle [denoted in the report by $PL(\alpha_i)$].
9	TDDEF	Real	USXORG, USYORG	2F8.0	(USXORG, USYORG) = Coordinates x,y (in system Oxyz) of point O (in meters) of segment O'B. O'B is normal to and intersects the tornado axes of translation. The direction of O'B is such that the tornado translation velocity vector must be rotated counterclockwise by 90° in order to be parallel to and have the same direction as O'B.
		Real Integer	LPTTD, DELTD NTD	2F8.0, I3	LPTTD = Length (in meters) of segment O'B [denoted in the report by b]. DELTD = Distance (in meters) equal to LPTTD/(NTD-1), where NDT is defined below [denoted in the report by ΔL]. NTD = The number of translation axes [denoted in the report by N_1]. Note: NDT is same for all angles AD(I).
		Real	$[PTD(I)]_1^{NTD}$	[5E12.5]	PTD(I) = Probability of occurrence of the I-th tornado translation axis [denoted in the report by $P(L_i)$].
10	BMDEF	Real	HWUSER	F8.0	HWUSER = The user specified tornado left or right width (in meters). It is used in the program only if no (finite) left or right width distances can be computed internally (see comment for variable LUSER, Group 7). Note: The left (right) widths is the the maximum orthogonal distance (in meters) to the left (right) of the tornado translation axis such that a stationary missile could still be moved (horizontally or vertically) by the tornado wind field.
		Integer, Real	TYPXBM, DELXBM	I3, F8.0	TYPXBM = 1 (Variable used internally in the program, indicating a set of basis missiles equally spaced on a straight line normal to tornado direction). DELXBM = Horizontal distance (in meters) between basis missiles.
		Integer, Real	TYPLBM, DELLBM	I3, F8.0	TYPZBM = 1 (Variable used internally in the program, indicating a set of basis missiles equally spaced on a vertical line). DELLBM = Vertical distance (in meters) between basis missiles.
		Real	T0, TDEL	2F8.0	

* [. . .] = means that this format is used repeatedly.

Description of Input Data for Stage 1 Program

Group	Module	Type	Variable Name(s)	Format	Description
10	BMDEF				T0 = Initial time (in seconds) to start a trajectory integration (suggested value T0 = 0.0). TDEL = Time interval (in seconds) between stored trajectory points (suggested value TDEL = 0.1 sec).
11	AMD	Integer Real Integer	N1AM [I, NC(1) NC(1) 1 [XCT, YCT, ZCT THETDX, DELX, DELY, DELZ NX, NY, NZ]] 1	I3, I6 7F8.0, 3I3	Note: This essentially repeats group 6 but with complete information about the lattices. There are N1AM sets of data. The 1-th set of data has NC(I) descriptors. Each descriptor describes a component lattice of NX*NY*NZ missiles. XCT, YCT, ZCT = Coordinates in Oxyz system (in meters) of one of the 4 corners of bottom horizontal plane of the lattice THETDX = A system of coordinates $O_L x_3 y_3 y_3$ is defined for each lattice, analogous to the system $O_c x_2 y_2 z_2$ for each hit region THETDX is the counterclockwise angle (in degrees) for which the vector Ox must be rotated in order to be parallel and have the same direction as the vector $O_L x_3$. DELX, DELY, DELZ = Missile separations in the lattice (in the x_3, y_3, z_3 directions, respectively).

Description of Input Data for Stage 2 Program

Group	Module	Type	Variable Name(s)	Format	Description
1	MAIN	Integer, Real, Integer, Real, Integer	PLEVEL, VCUT, MXNHVD, DELHV, NHVI	I2, E12.5, I12, E12.5, I12	PLEVEL = Determines the amount of output to the printer. Note: Each group of output starts with a preface of the form (P Level - Module). Here, <Level> is the minimum value that PLEVEL must have in order for that particular output to occur. If <Level> is null the output will always occur <Module> is the name of the Module where the printing is done. -1 ≤ Summary of all results 0 = (more output than -1) Input probabilities are listed. 1 ≥ (more output than 0) Hit velocities by distribution are listed. VCUT = Smallest value (in meters/sec) considered in histograms of hit velocities. MXNHVD = Maximum number of velocities of hitting missiles being listed (starting from largest velocity). DELHV = Interval (in meters/sec) in the velocity histogram. NHVI = The number of intervals in the velocity histograms starting from 0.0. Note: One extra interval is added at the high end to handle any velocities exceeding the velocity interval of the last bar.

```
C
C                              PTORWD1-STG1
C                              ------------
C
C     THIS IS THE MAIN MODULE OF A FORTRAN PROGRAM WHICH PERFORMS THE
C     FIRST STAGE OF A PROBABILISTIC ASSESSMENT OF TORNADO MISSILE
C     IMPACT VELOCITIES.
C
C------------------------------------------------------------------------
C
C                     --- APPLICATIONS PROGRAM ---
C
C  FOR GENERAL USE.
C
C  ADDITIONAL ROUTINES REQUIRED.
C
C     FOR THIS APPLICATION.
C
C        AD       BMDEF    DSCPHS   HIT      INITRJ
C        ADDEF    CRTRHS   FLUSH    HITGND   INTRSC
C        AMD      DELFCE   FVHRF    HITSRF   IXINT
C        AMDDEF   DIST     FVVRF    INDEX    LINTRP
C        BINARY   DRAG     GENTRJ   INFTRJ   MARK
C
C        MOVXY    PRBDEF   ROUNDD   TD       TRNXY
C        MSLTYP   PRNTED   ROUNDU   TDDEF    TTDEF
C        OUTBUF   PRV2D    SEARCH   TED      TTYP
C        PIV2D    RHS      SITE     TFHS     XBMJLU
C        PKRA     ROTXY    STORE    TORWDF
C
C     TOOLS.
C
C        DERT     R1MACH
C        INTRP    SSORT
C        I1MACH   STEP
C        ODERT
C        ROOT
C
C  COMMON.
C
C     DECLARATIONS APPEARING IN MAIN ARE REPEATED IN ROUTINES.
C
C        AD       DRAG     HITSRF   TDDEF    TTYP
C        ADDEF    FVHRF    MSLTYP   TED
C        AMD      FVVRF    PRBDEF   TFHS
C        BMDEF    GENTRJ   RHS      TORWDF
C        CRTRHS   HIT      TD       TTDEF
C
C  MAXIMUM PROBLEM SIZE DEFINED.
C
C     PARAMETER = CURRENT VALUE                     HOLDS
C
C     *  BUFSZE = 2500              SIZE OF OUTPUT BUFFER.
C
C                                      EFFECTS ARRAYS.
C                                         IN MAIN ---
C                                            BUFFER
```

```
C
C        MXNAD  = 20                        NUMBER OF ANGULAR DIRECTIONS.
C
C                                              EFFECTS ARRAYS.
C                                                 IN MAIN ---
C                                                    PAD
C                                                 IN COMMON ---
C                                                    ARTFV
C                                                    AOFTFV
C
C     *  MXNAM  = 1500                      NUMBER OF MISSILES IN ANY ACTUAL
C                                           MISSILE DISTRIBUTION.
C
C                                              EFFECTS ARRAYS.
C                                                 IN MAIN ---
C                                                    PRMAAM
C                                                    PRMGAM
C                                                    XAM
C                                                    YAM
C                                                    ZAM
C                                                    XAMTF
C                                                    YAMTF
C                                           MISSILE DISTRIBUTION.
C
C        MXNHR  = 10                        NUMBER OF HIT REGIONS.
C
C                                              EFFECTS ARRAYS.
C                                                 IN MAIN ---
C                                                    HSFCNT
C                                                    IFTRJ
C                                                    ILTRJ
C                                                    LKLSHS
C                                                    PERMHS
C                                                    XCHR
C                                                    YCHR
C                                                    ZCHR
C                                                    XCHRTF
C                                                    YCHRTF
C                                                 IN COMMON ---
C                                                    AFHS
C                                                    BFHS
C                                                    CFHS
C                                                    AFHSTF
C                                                    BFHSTF
C                                                    COEFHS
C                                                    XFHS
C                                                    YFHS
C                                                    ZFHS
C                                                    XFHSTF
C                                                    YFHSTF
C
C        MXNIAM = 10                        NUMBER OF ACTUAL MISSILE
C                                           DISTRIBUTIONS.
C
C                                              EFFECTS ARRAYS.
C                                                 IN MAIN ---
C                                                    NAM
C                                                    PAM
```

```
C
C     *  MXNLBM = 20                NUMBER OF LEVELS (IN Z) OF BASIS
C                                   MISSILES.
C
C                                      EFFECTS ARRAYS.
C                                         IN MAIN ---
C                                            LAM
C                                            LCBM
C                                            LPNT
C                                            MNXMPJ
C                                            MXXMPJ
C                                            YTRJLM
C
C        MXNTD  = 20                NUMBER OF TRANSLATION DISTANCES.
C
C                                      EFFECTS ARRAYS.
C                                         IN MAIN ---
C                                            PTD
C                                         IN COMMON ---
C                                            TDTFV
C
C     *  MXNTRJ = 1500              NUMBER OF TRAJECTORY POINTS IN ANY
C                                   BASIS MISSILE TRAJECTORY.
C
C                                      EFFECTS ARRAYS.
C                                         IN MAIN ---
C                                            TRJ
C
C        MXNTT  = 10                NUMBER OF TORNADO TYPES.
C
C                                      EFFECTS ARRAYS.
C                                         IN MAIN ---
C                                            PTT
C                                            TLWDTH
C                                            TRWDTH
C                                            TMNSTD
C                                            TMNTVT
C                                         IN COMMON ---
C                                            SOEV
C
C     *  MXNXBM = 1000              NUMBER OF BASIS MISSILES ALONG THE X
C                                   AXIS.
C
C                                      EFFECTS ARRAYS.
C                                         IN MAIN ---
C                                            XCBM
C                                            XCBML
C
C        MXNYTN = 100               NUMBER OF Y TRANSLATION INTERVALS.
C
C                                      EFFECTS ARRAYS.
C                                         IN MAIN ---
C                                            IFYTN
C                                            ILYTN
C                                            XMNYTN
C                                            XMXYTN
C                                            ZMNYTN
C                                            ZMXYTN
```

```
C
C    NOTE. * MEANS THAT THESE PARAMETERS ARE SET IN DATA STATEMENTS
C          AND MUST BE CHANGED IF THE CURRENT VALUES ARE CHANGED.
C
C ARRAY DIMENSION INFORMATION. (ADJUST TO MAXIMUM PROBLEM SIZE)
C
C          NAME            SIZE                   HOLDS
C
C    MAIN.
C
C       R) BUFFER(*)    BUFSZE              SORTED HIT INFORMATION READY
C                                           TO BE WRITTEN TO MASS STORAGE
C                                           FOR STAGE 2.
C
C       I) HSFCNT(*,    (6, MXNHR)          THE NUMBER OF HITS WHICH
C                 *)                        STRUCK EACH FACE OF EACH HIT
C                                           SURFACE.
C
C       R) IFTRJ(*)     MXNHR + 1           THE INDEX OF THE FIRST
C                                           TRAJECTORY POINT TO CONSIDER
C                                           FOR A HIT WITH EACH OF THE HIT
C                                           REGIONS.
C
C          ILTRJ(*)     MXNHR + 1           LIKE IFTRJ(*) EXCEPT THEY ARE
C                                           THE LAST INDICES.
C
C       I) IFYTN(*)     MXNYTN              THE INDICES OF THE FIRST POINT
C                                           OF THE TRAJECTORY THAT ENTERS
C                                           EACH Y TRANSLATION INTERVAL.
C
C          ILYTN(*)     MXNYTN              THE INDICES OF THE LAST POINT
C                                           OF THE TRAJECTORY THAT LEAVES
C                                           EACH Y TRANSLATION INTERVAL.
C
C       I) LAM(*)       MXNLBM              THE INDICES OF THE BASIS
C                                           MISSILE LEVELS NEEDED TO
C                                           HANDLE ALL ACTUAL MISSILES FOR
C                                           THE CURRENT ACTUAL MISSILE
C                                           DISTRIBUTION.
C
C       R) LCBM(*)      MXNLBM + 2          THE Z COORDINATES OF EACH
C                                           LEVEL.
C
C       I) LKLSHS(*)    MXNHR               A WORK VECTOR PASSED TO
C                                           SUBROUTINE HIT WHICH IS USED
C                                           TO STORE A ONE WAY LINKED LIST
C                                           THAT CONNECTS TOGETHER THE
C                                           SECTIONS OF TRAJECTORY TO
C                                           SEARCH FOR A POSSIBLE HIT.
C
C       I) LPNT(*)      MXNLBM + 1          THE INDICES OF THE START OF
C                                           EACH GROUP OF ACTUAL MISSILE
C                                           COORDINATES IN XAM, YAM, AND
C                                           ZAM ASSOCIATED WITH EACH
C                                           REQUIRED BASIS MISSILE LEVEL.
C
C       R) MNXMPJ(*)    MXNLBM              THE MINIMUM X PROJECTION OF
C                                           ALL ACTUAL MISSILES WITHIN
```

```
C                                        EACH OCCUPIED Z LEVEL FOR ALL
C                                        ANGLES OF ATTACK.
C
C         MXXMPJ(*)    MXNLBM            LIKE MNXMPJ(*) EXCEPT THEY ARE
C                                        MAXIMUM X PROJECTIONS.
C
C      I) NAM(*)       MXNIAM            THE NUMBER OF ACTUAL MISSILES
C                                        IN EACH DISTRIBUTION.
C
C      R) PAD(*)       MXNAD             THE PROBABILITY OF OCCURRENCE
C                                        OF EACH ANGULAR DIRECTION.
C
C      R) PAM(*)       MXNIAM            THE PROBABILITY OF OCCURRENCE
C                                        OF EACH ACTUAL MISSILE
C                                        DISTRIBUTION.
C
C      R) PRMAAM(*)    MXNAM             THE PERMUTATION VECTOR THAT
C                                        REFLECTS THE REORDERING BY
C                                        INCREASING Z OF ALL THE
C                                        MISSILES IN THE CURRENT SET OF
C                                        ACTUAL MISSILES.
C
C      R) PRMGAM(*)    MXNAM             THE PERMUTATION VECTOR
C                                        THAT REFLECTS THE REORDERING
C                                        BY INCREASING X OF THE ACTUAL
C                                        MISSILES ASSOCIATED WITH THE
C                                        CURRENT BASIS MISSILE LEVEL.
C
C      R) PERMHS(*)    MXNHR             A WORK VECTOR PASSED TO
C                                        SUBROUTINE HIT WHICH IS USED
C                                        AS A PERMUTATION VECTOR THAT
C                                        REFLECTS THE REORDERING BY
C                                        INCREASING Y OF THE SECTIONS
C                                        OF TRAJECTORY EACH
C                                        CORRESPONDING TO A HIT
C                                        SURFACE TO SEARCH FOR A
C                                        POSSIBLE HIT.
C
C      R) PTD(*)       MXNTD             THE PROBABILITY OF OCCURRENCE
C                                        OF EACH TRANSLATION DISTANCE.
C
C      R) PTT(*)       MXNTT             THE PROBABILITY OF OCCURRENCE
C                                        OF EACH TORNADO TYPE.
C
C      R) TLWDTH(*)    MXNTT             THE WIDTH OF THE TORNADO PATH
C                                        TO THE LEFT OF THE CENTER LINE
C                                        FOR EACH TORNADO TYPE.
C
C         TRWDTH(*)    MXNTT             LIKE TLWDTH(*) EXCEPT THEY ARE
C                                        WIDTHS TO THE RIGHT OF THE
C                                        CENTER LINE.
C
C      R) TMNSTD(*)    MXNTT             THE MINIMUM TOUCHDOWN DISTANCE
C                                        FOR EACH TORNADO TYPE.
C
C      R) TMNTVT(*)    MXNTT             THE MINIMUM TORNADO TRAVEL
C                                        TIME BEFORE A MISSILE CAN BE
C                                        DECLARED TO BE STATIONARY.
```

```
C
C      R) TRJ(*)      6 * MXNTRJ + 1      HOLDS THE 3 POSITION AND 3
C                                         VELOCITY COMPONENTS OF THE
C                                         BASIS MISSILE AT EQUALLY
C                                         SPACED TIME INTERVALS TDEL
C                                         ALONG THE TRAJECTORY.
C
C      R) XAM(*)      MXNAM               X COORDINATES OF THE ACTUAL
C                                         MISSILES GROUPED TOGETHER BY
C                                         LEVEL AND THE GROUPS ARRANGED
C                                         BY INCREASING LEVEL.
C
C         YAM(*)      MXNAM               LIKE XAM(*) EXCEPT THEY ARE
C                                         Y COORDINATES.
C
C         ZAM(*)      MXNAM               LIKE XAM(*) EXCEPT THEY ARE
C                                         Z COORDINATES.
C
C      R) XAMTF(*)    MXNAM               THE TRANSFORMED X COORDINATES
C                                         OF THE ACTUAL MISSILES
C                                         ASSOCIATED WITH THE CURRENT
C                                         BASIS MISSILE LEVEL.
C
C         YAMTF(*)    MXNAM               LIKE XAMSV(*) EXCEPT THEY ARE
C                                         Y COORDINATES.
C
C      R) XCBM(*)     MXNXBM + 2          THE X COORDINATES OF THE LINE
C                                         OF BASIS MISSILES WHICH ARE
C                                         USED TO GENERATE THE BASIS
C                                         MISSILES AT EACH LEVEL (IN Z).
C
C         XCBML(*)    MXNXBM + 2          THE X COORDINATES OF THE LINE
C                                         OF BASIS MISSILES FOR THE
C                                         CURRENT LEVEL.
C
C      R) XCHR(*)     4 * (MXNHR + 1)     BLOCKS OF 4 X CORDINATES FOR
C                                         THE 4 CORNER POINTS OF EITHER
C                                         THE TOP OR BOTTOM FACE OF THE
C                                         GLOBAL COVERING HIT REGION AND
C                                         EACH COMPONENT HIT REGION.
C
C         YCHR(*)     4 * (MXNHR + 1)     LIKE XCHR(*) EXCEPT THEY ARE
C                                         Y COORDINATES.
C
C         ZCHR(*)     2 * (MXNHR + 1)     BLOCKS OF 2 Z COORDINATES FOR
C                                         THE BOTTOM AND TOP FACES OF
C                                         THE GLOBAL COVERING HIT REGION
C                                         AND EACH COMPONENT HIT REGION.
C
C      R) XCHRTF(*)   4 * (MXNHR + 1)     THE TRANSFORMED BLOCKS OF 4 X
C                                         COORDINATES FOR THE 4 CORNER
C                                         POINTS OF EITHER THE TOP OR
C                                         BOTTOM FACE OF THE GLOBAL
C                                         COVERING HIT REGION AND EACH
C                                         COMPONENT HIT REGION.
C
C         YCHRTF(*)   4 * (MXNHR + 1)     LIKE XCHRTF(*) EXCEPT THEY ARE
C                                         Y COORDINATES.
```

```
C
C          R) XMNYTN(*)    MXNYTN              THE MINIMUM X VALUE OF THE
C                                              TRAJECTORY POINTS IN EACH Y
C                                              TRANSLATION INTERVAL.
C
C             XMXYTN(*)    MXNYTN              LIKE XMNYTN(*) EXCEPT THEY ARE
C                                              MAXIMUM X VALUES.
C
C          R) YTRJLM(*)    MXNLBM              THE Y TRAJECTORY LIMIT OF A
C                                              BASIS MISSILE TRAJECTORY AT
C                                              EACH REQUIRED BASIS MISSILE
C                                              LEVEL.
C
C          R) ZMNYTN(*)    MXNYTN              THE MINIMUM Z VALUE OF THE
C                                              TRAJECTORY POINTS IN EACH Y
C                                              TRANSLATION INTERVAL.
C
C             ZMXYTN(*)    MXNYTN              LIKE ZMNYTN(*) EXCEPT THEY ARE
C                                              MAXIMUM Z VALUES.
C      COMMON.
C
C          R) ARTFV(*)     MXNAD               EACH ANGLE (IN RADIANS)
C                                              CORRESPONDING TO EACH ANGLE OF
C                                              TORNADO ATTACK THAT ALL POINTS
C                                              MUST BE ROTATED BY IN ORDER
C                                              FOR THE TORNADO TO ALWAYS
C                                              TRANSLATE ALONG THE + Y AXIS
C                                              IN THE MISSILE REGION CENTERED
C                                              COORDINATE SYSTEM.
C
C          R) AOFTFV(*)    MXNAD               THE OFFSET FOR EACH ANGLE THAT
C                                              MUST BE ADDED TO EACH OF THE
C                                              TRANSLATION DISTANCES IN
C                                              TDTFV(*) TO CONVERT THE
C                                              TRANSLATION DISTANCES THAT
C                                              ASSUME A TORNADO TRANSLATING
C                                              ALONG THE + Y AXIS FROM A USER
C                                              COORDINATE SYSTEM TO A MISSILE
C                                              REGION CENTERED COORDINATE
C                                              SYSTEM.
C
C          R) AFHS(*)      6 * MXNHR           BLOCKS OF 6 X DIRECTION
C                                              NUMBERS FOR EACH OF THE 6
C                                              FACES OF EACH COMPONENT HIT
C                                              SURFACE.
C
C             BFHS(*)      6 * MXNHR           LIKE AFHS(*) EXCEPT THEY ARE
C                                              Y DIRECTION NUMBERS.
C
C             CFHS(*)      6 * MXNHR           LIKE AFHS(*) EXCEPT THEY ARE
C                                              Z DIRECTION NUMBERS.
C
C          R) AFHSTF(*)    6 * MXNHR           THE TRANSFORMED BLOCKS OF 6 X
C                                              DIRECTION NUMBERS FOR EACH OF
C                                              THE 6 FACES OF EACH COMPONENT
C                                              HIT SURFACE.
C
C             BFHSTF(*)    6 * MXNHR           LIKE AFHSTF(*) EXCEPT THEY ARE
```

```
C                                         Y DIRECTION NUMBERS.
C
C        R) COEFHS(*)   (4 * 6 * MXNHR)   A WORK VECTOR USED BY
C                                         SUBROUTINE HIT TO HOLD BLOCKS
C                                         OF 4 * 6 = 24 COEFFICIENTS
C                                         REQUIRED FOR DESCRIBING THE
C                                         6 FACIAL PLANES OF EACH HIT
C                                         SURFACE THAT COULD POSSIBLY
C                                         BE HIT BY THE CURRENT
C                                         TRAJECTORY. THE ORDER OF THE
C                                         HIT SURFACES IS GIVEN BY THE
C                                         PERMUTATION VECTOR PERMHS(*)
C                                         DECLARED IN MAIN.
C
C        R) SOEV(*)     MXNTT             MAXIMUM WIND VELOCITY (IN
C                                         MILES PER HOUR) FOR EACH
C                                         TORNADO TYPE.
C
C        R) TDTFV(*)    MXNTD             EACH TRANSLATION DISTANCE
C                                         TAKEN ALONG THE X AXIS
C                                         ASSUMING A TORNADO TRANSLATING
C                                         ALONG THE + Y AXIS IN A USER
C                                         COORDINATE SYSTEM TRANSLATED
C                                         FROM THE REFERENCE COORDINATE
C                                         SYSTEM.
C
C        R) XFHS(*)     6 * MXNHR         BLOCKS OF 6 X COORDINATES FOR
C                                         EACH OF THE 6 FACES OF EACH
C                                         COMPONENT HIT SURFACE.
C
C           YFHS(*)     6 * MXNHR         LIKE XFHS(*) EXCEPT THEY ARE
C                                         Y COORDINATES.
C
C           ZFHS(*)     6 * MXNHR         LIKE XFHS(*) EXCEPT THEY ARE
C                                         Z COORDINATES.
C
C        R) XFHSTF(*)   6 * MXNHR         THE TRANSORMED BLOCKS OF 6 X
C                                         COORDINATES FOR EACH OF THE 6
C                                         FACES OF EACH COMPONENT HIT
C                                         SURFACE.
C
C           YFHSTF(*)   6 * MXNHR         LIKE XFHSTF(*) EXCEPT THEY ARE
C                                         Y COORDINATES.
C
C  FILES.
C
C    UNIT                     DESCRIPTION
C
C      5        STANDARD INPUT FILE.
C
C      6        STANDARD OUTPUT FILE.
C
C      8        MASS STORAGE FILE TO WHICH ALL TRAJECTORY INFORMATION IS
C               WRITTEN IN BINARY FORM TO BE READ BY THE STAGE 2
C               PROGRAM.
C
C  USAGE NOTES.
C
```

```
C     BEFORE COMPILING ---
C
C        1) ADJUST ARRAY SIZES AS REQUIRED TO CONFORM TO THE MAXIMUM
C           SIZE PROBLEM YOU PLAN TO RUN.
C
C        2) IN ROUTINES I1MACH AND R1MACH THE DESIRED SET OF DATA
C           STATEMENTS APPROPRIATE TO YOUR MACHINE MUST BE ACTIVATED BY
C           REMOVING THE C FROM COLUMN 1. IF DATA STATEMENTS DO NOT EXIT
C           FOR YOUR MACHINE USE THE DOCUMENTATION IN EACH ROUTINE AND
C           YOUR MACHINE REFERENCE MANUAL TO DETERMINE THE CONSTANTS.
C
C           REMEMBER.   A) I1MACH AND R1MACH CONTAIN THE ONLY MACHINE
C                          DEPENDENT CONSTANTS IN THE WHOLE PROGRAM.
C
C                       B) DO NOT FORGET THAT THE DATA STATEMENT FOR
C                          IMACH(17) AT THE BOTTON CF I1MACH DEFINES
C                          OUTPUT UNIT 8.
C
C  BY, MARTIN CORDES
C      CENTER FOR APPLIED MATHEMATICS
C      NATIONAL BUREAU OF STANDARDS
C      WASHINGTON, D.C. 20234
C      (301) 921-2631
C
C      VERSICN 1     DECEMBER 1979
C      UPDATE  1     MARCH    1980
C
C-----------------------------------------------------------------------
C  COMMCN DECLARATICNS.
C-----------------------------------------------------------------------
C
      REAL SOEV(20), ARTFV(20), AOFTFV(20), TDTFV(20),
     *     XFHS(60), YFHS(60), ZFHS(60), XFHSTF(60), YFHSTF(60),
     *     AFHS(60), BFHS(60), CFHS(60), AFHSTF(60), BFHSTF(60),
     *     COEFHS(240)
      REAL CCRAG, AREA, MASS, RFC, RMXRTS, SO, STF, VXTF, VYTF, THETAC,
     *     XOTF, YOTF, TOTF
      INTEGER JPN, JSA, JHS, JMT, IIAM, ITT, IAD, ITD, IBM
C
      COMMON /PRBPR/ JPN, JSA, JHS, JMT, IIAM, ITT, IAD, ITD, IBM
      COMMCN /TRJPR/ CDRAG, AREA, MASS, RFC,
     *               RMXRTS, SO, STF, VXTF, VYTF, THETAC,
     *               XOTF, YOTF, TOTF
      COMMON /VECPR/ SOEV, ARTFV, AOFTFV, TDTFV
      COMMCN /HRSPR/ XFHS, YFHS, ZFHS, XFHSTF, YFHSTF,
     *               AFHS, BFHS, CFHS, AFHSTF, BFHSTF,
     *               COEFHS
C
C-----------------------------------------------------------------------
C
C  CODE.
C
      REAL XCMR(4), YCMR(4), ZCMR(2), XCHR(44), YCHR(44), ZCHR(22),
     *     PAM(10), PTT(20), TLWDTH(20), TRWDTH(20),
     *     TMNSTD(20), TMNTVT(20), PAD(20), PTD(10), XCBM(1002),
     *     LCBM(22), XAM(1500), YAM(1500), ZAM(1500), YTRJLM(20),
     *     XAMTF(1500), YAMTF(1500), PRMAAM(1500), XCHRTF(44),
     *     YCHRTF(44), TRJ(9001), XMNYTN(100), XMXYTN(100), ZMNYTN(100),
     *      MNXMPJ(20), MXXMPJ(20), XCBML(1002), IFTRJ(11), ILTRJ(11),
     *      PERMHS(10), PRMGAM(1500), HPT(3), ZMXYTN(100), BUFFER(2500)
      REAL DELYTN, TNXORG, TNYORG, TO, TDEL, ADTF, TDTF, YMNTRJ, YMXTRJ,
     *      DELXAM, DELYAM, DELZAM, HV, HITFAC, MNTNMR, MXTNMR,
     *      DUMMY, VHMX, VVMX, XJAM, YJAM, ZJAM, C, S, XH, YH, ZH
      INTEGER HSFCNT(6, 10)
      INTEGER LAM(20), LPNT(21), IFYTN(100), ILYTN(100), NAM(10),
     *         LKLSHS(10)
      INTEGER SIU, SOU, BUFPNT, PLEVEL, NHR, NIAM, NTT, NAD, NTD, NXBM,
     *         NLBM, IAM, NMH, NMT, NMTS, NLAM, JTT, NH, I, JLAM,
     *         JLBM, JXBM, JAD, NAMJL, IXJL, NCHR, JTD, ILXAM, IUXAM,
     *         NTRJ, FGTRJ, IMNYTN, IMXYTN, JPAM, JZAM, TM,
     *         IDN, TWORST, JHSRF, JFACE, JAM, JHTRJ, J
      LOGICAL GENBM
C
      INTEGER I1MACH
C
      INTEGER BUFSZE, MXNAM, MXNLBM, MXNTRJ, MXNXBM
C
      DATA BUFSZE / 2500/,
     *      MXNAM  / 1500/,
     *      MXNLBM /   20/,
     *      MXNTRJ / 1500/,
     *      MXNXBM / 1000/
C
      SIU = I1MACH(1)
      SOU = I1MACH(2)
      BUFPNT = 0
C
C  -----
C  INPUT PRINT LEVEL.
C  -----
C
      READ (SIU, 1100) PLEVEL
 1100 FORMAT (I2)
C
C  DEFINE PROBLEM.
C
      CALL PRBDEF (PLEVEL)
      CALL SITE (PLEVEL, DELYTN, TNXORG, TNYORG, XCMR, YCMR, ZCMR)
      CALL HITSRF (PLEVEL, NHR, XCHR, YCHR, ZCHR)
      CALL MSLTYP (PLEVEL)
      CALL AMDDEF (PLEVEL, MXNAM, NIAM, NAM, PAM)
      CALL TTDEF (PLEVEL, NTT, PTT, TWORST, TMNSTD, TMNTVT)
      CALL ADDEF (PLEVEL, NAD, PAD)
      CALL TDDEF (PLEVEL, TNXORG, TNYORG, NAD, NTD, PTD)
      CALL BMDEF (PLEVEL, MXNXBM, MXNLBM, TWORST, XCMR, YCMR, ZCMR, NTT,
     *            NAD, NTD, TLWDTH, TRWDTH, MNTNMR, MXTNMR, NXBM, XCBM,
     *            NLBM, LCBM, TO, TDEL)
C
C  ------
C  OUTPUT TORNADO PATH INFORMATION.
C  ------
C
      IF (PLEVEL .GE. -1)
     *   WRITE (SOU, 1150) (I, TMNSTD(I), TLWDTH(I), TRWDTH(I),
     *                      I = 1, NTT)
 1150    FORMAT (11H0(P-1-MAIN) / 1H , 3X, 19HNOTE, THE FOLLOWING,
     *             32H VALUES ARE ALWAYS OVERESTIMATES / 1H0, 5X,
     *             7HTORNADO, 5X, 25HSTARTING MINIMUM DISTANCE, 10X,
     *             20HEFFECTIVE LEFT WIDTH, 9X,
     *             21HEFFFCTIVE RIGHT WIDTH // (1H , I12, 3(18X,
     *             1PE12.5)))
C
C ------
C OUTPUT PROBLEM HEADING.
C ------
C
      IF (PLEVEL .GE. -1)
     *   WRITE (SOU, 1200) JPN
 1200    FORMAT (12H0(P-1-MAIN) / 1H , 3X, 8HPROBLEM , I12,
     *             10H --- START / 1H0, 6X, 9X, 3HIAM, 4X, 8HNAM(IAM), 9X,
     *             3HNMH, 9X, 3HNMT, 8X, 4HNMTS, 6X, 6HHITFAC)
C
C INITIALIZATIONS.
C
      DO 1250 J = 1, NHR
         DO 1225 I = 1, 6
            HSFCNT(I, J) = 0
 1225    CONTINUE
 1250 CONTINUE
C
C LOOP 0, FOR EACH SET OF BASIS MISSILES.
C
      DO 2300 IAM = 1, NIAM
C
         NMH = 0
         NMT = 0
         NMTS = 0
C
C GET ACTUAL MISSILE DISTRIBUTION.
C
         CALL AMD (PLEVEL, IAM, NAM, TNXORG, TNYORG, XCHR, YCHR, NLBM,
     *                LCBM, NAD, XAM, YAM, ZAM, NLAM, LAM, LPNT, MNXMPJ,
     *                MXXMPJ, YTRJLM, PRMAAM)
C
C LOOP 1. FOR EACH TORNADO TYPE.
C
         DO 2200 JTT = 1, NTT
C
            NH = 0
C
            CALL TTYP (PLEVEL, TMNSTD(JTT), JTT)
C
C LOOP 2, FOR EACH BASIS MISSILE LEVEL (IN Z) NEEDED TO COVER THE
C         ACTUAL MISSILES.
C
            DO 2100 JLAM = 1, NLAM
C
               JLBM = LAM(JLAM)
               CALL XBMJLU (PLEVEL, NXBM, XCBM, TLWDTH(JTT),
     *                         TRWDTH(JTT), MNTNMR, MXTNMR, MNXMPJ(JLAM),
     *                         MXXMPJ(JLAM), NXBML, XCBML)
C
C LOOP 3. FOR EACH BASIS MISSILE (IN X) NEEDED TO COVER ALL THE ANGLES
C         AND TRANSLATIONS.
```

```
C
           DO 2000 JXBM = 1, NXBML
C
              GENBM = .FALSE.
C
C LOOP 4. FOR EACH ANGULAR DIRECTION.
C
              DO 1900 JAD = 1, NAD
                CALL AD (PLEVEL, JAD, ADTF)
C
C MOVE, TRANSLATE TO THE MISSILE REGION CENTERED COORDINATE SYSTEM, AND
C ROTATE THE INITIAL POSITIONS OF THE ACTUAL MISSILES ASSOCIATED WITH
C LEVEL JLBM. NEXT, SORT THEIR X POSITIONS IN ASCENDING ORDER. THE SORT
C CARRIES ALONG THE Y POSITIONS AND A PERMUTATION VECTOR.
C
                NAMJL = LPNT(JLAM + 1) - LPNT(JLAM)
                IXJL = LPNT(JLAM)
C
                CALL MOVXY (NAMJL, XAM(IXJL), YAM(IXJL), XAMTF,
    *                     YAMTF)
                CALL TRNXY (TNXORG, TNYORG, NAMJL, XAMTF, YAMTF)
                CALL ROTXY (ADTF, NAMJL, XAMTF, YAMTF)
                CALL SSORT (XAMTF, YAMTF, DUMMY, PRMGAM, NAMJL, 3)
C
C MOVE, TRANSLATE TO THE MISSILE REGION CENTERED COORDINATE SYSTEM, AND
C ROTATE ALL COVERING HIT REGIONS.
C
                NCHR = (NHR + 1) * 4
C
                CALL MOVXY (NCHR, XCHR, YCHR, XCHRTF, YCHRTF)
                CALL TRNXY (TNXORG, TNYORG, NCHR, XCHRTF, YCHRTF)
                CALL ROTXY (ADTF, NCHR, XCHRTF, YCHRTF)
C
C MOVE, TRANSLATE TO THE MISSILE REGION CENTERED COORDINATE SYSTEM, AND
C ROTATE ALL HIT SURFACES.
C
                CALL TFHS (TNXORG, TNYORG, ADTF, NHR)
C
C LOOP 5. FOR EACH TRANSLATION DIRECTION.
C
                DO 1800 JTD = 1, NTD
                   CALL TD (PLEVEL, JAD, JTD, TDTF)
C
C SEARCH FOR THE SUBSET OF ACTUAL MISSILES THAT HAVE X COORDINATES
C CLOSE ENOUGH TO THE X COORDINATE OF THE STARTING POINT OF THE
C GENERATED BASIS TRAJECTORY.
C
                   CALL SEARCH (PLEVEL, JXBM, XCBML, NAMJL, XAMTF,
    *                          YAMTF, TDTF, ILXAM, IUXAM)
C
C IF THE INTERVAL IS EMPTY BRANCH TO THE END OF LOOP 5.
C
                   IF ((ILXAM .EQ. 0) .AND. (IUXAM .EQ. 0))
    *                GO TO 1800
C
                     IF (GENBM) GO TO 1400
C
C INITIALIZE TRAJECTORY INFORMATION, GENERATE THE TRAJECTORY, AND
```

```
C  GENERATE AUXILARY INFORMATION ABOUT THE TRAJECTORY.
C
                              GENBM = .TRUE.
                              CALL INITRJ (JLBM. LCBM. JXBM. XCBML.
     *                                 TRJ. TMNSTD(JTT))
                              CALL GENTRJ (PLEVEL. TO. TDEL.
     *                                 TMNTVT(JTT). YTRJLM(JLAM).
     *                                 MXNTRJ. NTRJ. TRJ. YMNTRJ.
     *                                 YMXTRJ. VHMX. VVMX. FGTRJ)
C
C  ------
C  OUTPUT TRAJECTCRY INFORMATION.
C  ------
C
                              IF (PLEVEL .GE. 1)
                                 WRITE (SOU. 1350) IAM. JTT. JLBM. JXBM.
     *                                             NTRJ. FGTRJ. TRJ(1).
     *                                             TRJ(2). TRJ(3).
     *                                             YMNTRJ. YMXTRJ. VHMX.
     *                                             VVMX
 1350                            FORMAT (10HO(P1-MAIN) / IH . 6X. 3HIAM.
     *                                 1X. 3HJTT. 1X. 4HJLBM. 1X.
     *                                 4HJXBM. 1X. 4HNTRJ. 1X.
     *                                 5HFGTRJ. 10X. 2HX0. IOX. 2HY0.
     *                                 10X. 2HZ0. 6X. 6HYMNTRJ. 6X.
     *                                 6HYMXTRJ. 8X. 4HVHMX. 8X.
     *                                 4HVVMX / 1H . 6X. I3. 1X. I3.
     *                                 1X. I4. IX. I4. 1X. I4. 5X. I1.
     *                                 7(1PE12.5)/)
C
                              IF (FGTRJ .EQ. 3) GO TO 1400
                              CALL INFTRJ (PLEVEL. NTRJ. TRJ. YMNTRJ.
     *                                 YMXTRJ. DELYTN. IMNYTN.
     *                                 IMXYTN. IFYTN. ILYTN. XMNYTN.
     *                                 XMXYTN. ZMNYTN. ZMXYTN)
C
C  LOOP 6. FOR EACH ACTUAL MISSILE.
C
 1400                      DO 1700 JPAM = ILXAM. IUXAM
C
C  DETERMINE THE INTERVAL OF THE TRAJECTORY TO SEARCH FOR A HIT FOR THE
C  GLOBAL COVERING HIT REGION AND IF THIS IS NONZERC FOR EACH COMPONENT
C  HIT REGION.
C
                              JZAM = IFIX (PRMGAM(JPAM)) + IXJL - 1
                              CALL INDEX (PLEVEL. XAMTF(JPAM).
     *                                YAMTF(JPAM). ZAM(JZAM). TDTF.
     *                                NHR. XCHRTF. YCHRTF. ZCHR.
     *                                DELYTN. NTRJ. TRJ.
     *                                IMNYTN. IMXYTN. IFYTN. ILYTN.
     *                                XMNYTN. XMXYTN. ZMNYTN.
     *                                ZMXYTN. FGTRJ. TM. IFTRJ.
     *                                ILTRJ. DELXAM. DELYAM. DELZAM)
C
                              IF (TM .EQ. 0) GO TO 1410
                                 NMTS = NMTS + 1
                                 HV = 0.0
                                 GO TO 1600
 1410                  IF ((IFIX (IFTRJ(1)) .EQ. 0) .AND.
     *                    (IFIX (ILTRJ(1)) .EQ. 0)) GO TO 1500
C
C  A HIT SEEMS POSSIBLE SO DETERMINE IF IT DOES OCCUR AND RETURN THE
C  REQUIRED COLLISICN INFORMATION.
C
                         CALL HIT (PLEVEL, TDTF, NHR, IFTRJ(2),
     *                             ILTRJ(2), DELXAM, DELYAM,
     *                             DELZAM, NTRJ, TRJ, HV, JHSRF,
     *                             JFACE, HPT, JHTRJ, PERMHS,
     *                             LKLSHS)
C
                         IF (HV .EQ. 0.0) GC TO 1600
C
C  THERE WAS A HIT.
C
                           NH = NH + 1
                           IDN = NTD * NAD * NTT * (IAM - 1) +
     *                           NTD * NAD * (JTT - 1) +
     *                           NTD * (JAD - 1) +
     *                           JTD
                           NMH = NMH + 1
C
C  PASS THE DISTRIBUTION NUMBER AND THE HIT VELOCITY TO BE PACKED IN THE
C  BUFFER AND UPDATE THE HIT COUNTS BY SURFACE AND FACE.
C
                           CALL STORE (PLEVEL, IDN, HV, BUFPNT,
     *                                 BUFSZE, BUFFER)
                           HSFCNT(JFACE, JHSRF) =
     *                           HSFCNT(JFACE, JHSRF) + 1
                           GO TO 1600
C
C  THERE WAS NOT A HIT.
C
 1500                  HV = 0.0
C
 1600                  NMT = NMT + 1
C
C  COMPUTE QUANTITIES FOR EVENT DESCRIPTOR.
C
                       JAM = IFIX (PRMAAM(JZAM))
                       C = COS (- ADTF)
                       S = SIN (- ADTF)
                       XJAM = C * XAMTF(JPAM) - S * YAMTF(JPAM)
     *                      - TNXORG
                       YJAM = S * XAMTF(JPAM) + C * YAMTF(JPAM)
     *                      - TNYORG
                       ZJAM = ZAM(JZAM)
                       XH = C * (HPT(1) - TDTF) - S * HPT(2)
     *                    - TNXORG
                       YH = S * (HPT(1) - TDTF) + C * HPT(2)
     *                    - TNYORG
                       ZH = HPT(3)
C
                       CALL PRNTED (PLEVEL, NMT, IAM, JTT, JAD,
     *                              JTD, JAM, XJAM, YJAM, ZJAM,
     *                              TM, HV, JHSRF, JFACE, XH, YH,
     *                              ZH, JHTRJ)
```

```
C
 1700                 CONTINUE
 1800             CONTINUE
 1900           CONTINUE
 2000         CONTINUE
 2100       CONTINUE
C
C ALL EVENTS FOR THE LAST NTD * NAD DISTRIBUTIONS HAVE BEEN GENERATED.
C IF THERE WAS AT LEAST ONE HIT THEN PACK THE BUFFER WITH A SPECIAL
C MARKING DESCRIPTOR,
C
            IF (NH .NE. 0) CALL MARK (BUFPNT, BUFSZE, BUFFER)
 2200     CONTINUE
C
C COMPUTE THE HIT FACTOR.
C
          HITFAC = FLOAT (NMH) / FLOAT (NTD * NAD * NTT * NAM(IAM))
C
C ------
C OUTPUT RESULTS FOR ONE ACTUAL MISSILE DISTRIBUTICN.
C ------
C
          IF (PLEVEL .GE. -1)
     *        WRITE (SOU, 2250) IAM, NAM(IAM), NMH, NMT, NMTS, HITFAC
 2250         FORMAT (1H , 6X, 5I12, 1PE12.5)
C
 2300 CONTINUE
C
C PACK THE BUFFER WITH THE TERMINATING DESCRIPTOR AND THEN FLUSH THE
C BUFFER BEFORE FINISHING.
C
      CALL FLUSH (BUFPNT, BUFSZE, BUFFER)
C
C ------
C OUTPUT THE HIT COUNTS BY SURFACE AND FACE.
C ------
C
      IF (PLEVEL .GE. -1)
     *    WRITE (SOU, 2350) (J, (HSFCNT(I, J), I = 1, 6), J = 1, NHR)
 2350     FORMAT (11H0(P-1-MAIN) / 1H , 3X, 25HHIT COUNTS BY SURFACE AND,
     *               5H FACE / 1H0, 3X, 7HSURFACE, 5X, 6HFACE 1, 3X,
     *               6HFACE 2, 3X, 6HFACE 3, 3X, 6HFACE 4, 3X, 6HFACE 5, 3X,
     *               6HFACE 6 // (1H , 7X, I3, 2X, 6(3X, I6)))
C
C ------
C OUTPUT PROBLEM ENDING.
C ------
C
      IF (PLEVEL .GE. -1)
     *    WRITE (SOU, 2400) JPN
 2400     FORMAT (1H0, 3X, 8HPROBLEM , I12, 9H --- STOP)
C
      STOP
      END
END PRT

@PRT,S PTORWDF-DOC.MARKEDDATA1/CASE5
```

```
SIMIU30*PTORWDF-DOC(1).MARKEDDATA1/CASES(1)
     1        1) MAIN    <C1   .L1   >-1
     2        2) PRBDEF  <C1   .L1   >  0   0   0   0   0   0   0   0   0
     3        3) SITE    <C1   .L2   >     50.0
     4           *                   >    135.0  -100.0       0.0    750.0    500.0      0.0
     5        4) HITSRF  <C2   .L2   >  1
     6           *                   >     32.5     50.0      0.0      0.0     40.0     40.0     60.0
     7        5) MSLTYP  <C21  .L1   >      1.5      3.8   1810.0      0.5
     8        6) AMDDEF  <C1   .L7   >  1
     9           *                   >  1       4
    10           *                   >  2   1   1
    11           *                   > 15   2   1
    12           *                   >  1   1   1
    13           *                   > 14  20   1
    14           *                   >        1.0E0
    15        7) TTDEF   <C1   .L3   >    140.0     46.0  1
    16           *                   >    360.0
    17           *                   >        1.000E0
    18        8) ADDEF   <C1   .L3   >  1
    19           *                   >     22.0
    20           *                   >        1.0E0
    21        9) TDDEF   <C1   .L6   >    135.0  -100.0
    22           *                   >   -150.0     10.0 16
    23           *                   >       0.06E0        0.06E0        0.06E0        0.06E0        0.06E0
    24           *                   >       0.06E0        0.06E0        0.06E0        0.06E0        0.06E0
    25           *                   >       0.06E0        0.06E0        0.07E0        0.07E0        0.07E0
    26           *                   >       0.07E0
    27       10)BMDEF    <C1   .L4   >    600.0
    28           *                   >  1       5.0
    29           *                   >  1      40.0
    30           *                   >      0.0       0.1
    31       11)AMD      <C11  .L5   >  1       4
    32           *                   >   -170.0  -120.0       0.0      0.0     30.0      0.0      0.0  2  1  1
    33           *                   >   -120.0  -100.0       0.0      0.0      3.0      2.0      0.0 15  2  1
    34           *                   >    -70.0   -25.0       0.0      0.0      0.0      0.0      0.0  1  1  1
    35           *                   >     60.0  -100.0       0.0      0.0     11.0      3.0      0.0 14 20  1
  END PRT

@PRT.S PTORWDF-DOC.DATA1/CASES
```

```
SIMIOFD*PTORWDF-DCC(1).DATA1/CASE5(0)
     1       -1
     2         0   0   0   0   0   0   0   0   0
     3           50.0
     4          135.0  -100.0      0.0    750.0    500.0      0.0
     5         1
     6           32.5     50.0      0.0      0.0     40.0     40.0     60.0
     7            1.5      3.8   1810.0      0.5
     8         1
     9         1      4
    10         2   1   1
    11        15   2   1
    12         1   1   1
    13        14  20   1
    14              1.0E0
    15          140.0     46.0   1
    16          360.0
    17            1.000E0
    18         1
    19           22.0
    20              1.0E0
    21          135.0  -100.0
    22         -150.0     10.0  16
    23             0.06E0      0.06E0      0.06E0      0.06E0      0.06E0
    24             0.06E0      0.06E0      0.06E0      0.06E0      0.06E0
    25             0.06E0      0.06E0      0.07E0      0.07E0      0.07E0
    26             0.07E0
    27          600.0
    28         1      5.0
    29         1     40.0
    30           0.0      0.1
    31         1      4
    32         -170.0  -120.0      0.0      0.0     30.0      0.0      0.0  2   1   1
    33         -120.0  -100.0      0.0      0.0      3.0      2.0      0.0 15   2   1
    34          -70.0   -25.0      0.0      0.0      0.0      0.0      0.0  1   1   1
    35           60.0  -100.0      0.0      0.0     11.0      3.0      0.0 14  20   1
  END PRT

@HDG.N .L.0
```

```
@XQT PTORWDF-DOC.STG1

 (P-1-MAIN)
    NOTE. THE FOLLOWING VALUES ARE ALWAYS OVERESTIMATES

      TORNADO     STARTING MINIMUM DISTANCE          EFFECTIVE LEFT WIDTH         EFFECTIVE RIGHT WIDTH

          1                    1.61875+02                     -1.06675+02                     3.27461+02

 (P-1-MAIN)
    PROBLEM             0 --- START

                IAM    NAM(IAM)          NMH         NMT          NMTS      HITFAC
                  1         313          506        5009             0  1.01038-01

 (P-1-MAIN)
    HIT COUNTS BY SURFACE AND FACE

    SURFACE      FACE 1   FACE 2   FACE 3   FACE 4   FACE 5   FACE 6

         1         329      167        0       11        0        0

    PROBLEM             0 --- STOP

@PRT,S PTORWDF-DOC.MAIN-STG2/CORDES80
FURPUR 28R1 U1 E33 S74T11 06/22/80 15:51:10
```

```
SIMI060*PTORWDF-DOC(1).MAIN-STG2/CORDES80(32)
C
C                              PTORWD1-STG2
C                              ------------
C
C     THIS IS THE MAIN MODULE OF A FORTRAN PROGRAM WHICH PERFORMS THE
C     SECOND STAGE OF A PROBABILISTIC ASSESSMENT OF TORNADO MISSILE
C     IMPACT VELOCITIES.
C
C-----------------------------------------------------------------------
C
C                      --- APPLICATIONS PROGRAM ---
C
C  FOR GENERAL USE.
C
C  ADDITIONAL ROUTINES REQUIRED.
C
C     FOR THIS APPLICATION.
C
C        GETHVD   PIV2D
C        GETPRB   PRV2D
C        HPROB    UNPKRA
C        INBUF
C        PDIST
C
C     TOOLS.
C
C        I1MACH
C        SSORT
C
C  MAXIMUM PROBLEM SIZE DEFINED.
C
C     PARAMETER = CURRENT VALUE                     HOLDS
C
C     *  MXBFSZ = 2500              SIZE OF INPUT BUFFER.
C                                   NOTE. THIS MUST BE AS LARGE AS
C                                         BUFSZE USED IN THE STAGE 1
C                                         PROGRAM.
C
C                                      EFFECTS ARRAYS.
C                                         IN MAIN ---
C                                            BUFFER
C
C        MXHVI  = 500               NUMBER OF HIT VELOCITY INTERVALS.
C
C                                      EFFECTS ARRAYS.
C                                         IN MAIN ---
C                                            HVCPB
C                                            HVICNT
C
C        MXNAD  = 20                NUMBER OF ANGULAR DIRECTIONS.
C
C                                      EFFECTS ARRAYS.
C                                         IN MAIN ---
C                                            PAD
C
C     *  MXNHV  = 20000             NUMBER OF HIT VELOCITIES.
C
```

```
C                                      EFFECTS ARRAYS.
C                                         IN MAIN ---
C                                            AMDN
C                                            AMHV
C
C        MXNIAM = 10                   NUMBER OF ACTUAL MISSILE
C                                      DISTRIBUTIONS.
C
C                                      EFFECTS ARRAYS.
C                                         IN MAIN ---
C                                            NAM
C                                            PAM
C
C        MXNTD  = 20                   NUMBER OF TRANSLATION DISTANCES.
C
C                                      EFFECTS ARRAYS.
C                                         IN MAIN ---
C                                            PTD
C
C        MXNTT  = 10                   NUMBER OF TORNADO TYPES.
C
C                                      EFFECTS ARRAYS.
C                                         IN MAIN ---
C                                            PTT
C
C     NOTE. * MEANS THAT THESE PARAMETERS ARE SET IN DATA STATEMENTS
C             AND MUST BE CHANGED IF THE CURRENT VALUES ARE CHANGED.
C
C  ARRAY DIMENSION INFORMATION. (ADJUST TO MAXIMUM PROBLEM SIZE)
C
C           NAME           SIZE                    HOLDS
C
C     MAIN.
C
C        R) AMDN(*)     MXNHV                MISSILE DISTRIBUTION NUMBERS
C                                            OF ALL MISSILES WITH HIT
C                                            VELOCITIES ABOVE CUTOFF.
C
C        R) AMHV(*)     MXNHV                ALL HIT VELOCITIES ABOVE
C                                            CUTOFF SORTED IN DESCENDING
C                                            ORDER.
C
C        R) BUFFER(*)   MXBFSZ               SORTED HIT INFORMATION READ
C                                            FROM MASS STORAGE.
C
C        R) HVCPB(*)    (MXHVI + 1)          FOR EACH HIT VELOCITY INTERVAL
C                                            THE PROBABILITY THAT A HIT
C                                            WILL HAVE A VELOCITY IN OR
C                                            EXCEEDING THE INTERVAL.
C
C        I) HVICNT(*)   (MXHVI + 1)          HIT VELOCITY INTERVAL COUNTS.
C
C        I) NAM(*)      MXNIAM               THE NUMBER OF ACTUAL MISSILES
C                                            IN EACH DISTRIBUTION.
C
C        R) PAD(*)      MXNAD                THE PROBABILITY OF OCCURRENCE
C                                            OF EACH ANGULAR DIRECTION.
C
```

```
C         R) PAM(*)      MXNIAM              THE PROBABILITY OF OCCURRENCE
C                                            OF EACH ACTUAL MISSILE
C                                            DISTRIBUTION.
C
C         R) PTD(*)      MXNTD               THE PROBABILITY OF OCCURRENCE
C                                            OF EACH TRANSLATION DISTANCE.
C
C         R) PTT(*)      MXNTT               THE PROBABILITY OF OCCURRENCE
C                                            OF EACH TORNADO TYPE.
C
C  FILES.
C
C     UNIT                    DESCRIPTION
C
C      5          STANDARD INPUT FILE.
C
C      6          STANDARD OUTPUT FILE.
C
C      8          MASS STORAGE FILE CREATED BY THE STAGE 1 PROGRAM FROM
C                 WHICH TRAJECTORY INFORMATION IS READ IN BINARY FORM.
C
C  USAGE NOTES.
C
C     BEFORE COMPILING ---
C
C        1) ADJUST ARRAY SIZES AS REQUIRED TO MEET YOUR OUTPUT
C           REQUIREMENTS AND TO CONFORM TO THE MAXIMUM SIZE PROBLEM
C           TO BE RUN BY THE STAGE 1 PROGRAM.
C
C        2) IN ROUTINE I1MACH THE DESIRED SET OF DATA STATEMENTS
C           APPROPRIATE TO YOUR MACHINE MUST BE ACTIVATED BY REMOVING
C           THE C FROM COLUMN 1. IF DATA STATEMENTS DO NOT EXIT FOR YOUR
C           MACHINE USE THE DOCUMENTATION IN THE ROUTINE AND YOUR
C           MACHINE REFERENCE MANUAL TO DETERMING THE CONSTANTS.
C
C           REMEMBER.   A) I1MACH CONTAINS THE ONLY MACHINE DEPENDENT
C                          CONSTANTS IN THE WHOLE PROGRAM.
C
C                       B) DO NOT FORGET THAT THE DATA STAEMENT FOR
C                          IMACH(17) AT THE BOTTOM OF I1MACH DEFINES
C                          OUTPUT UNIT 8.
C
C  BY. MARTIN CORDES
C      CENTER FOR APPLIED MATHEMATICS
C      NATICNAL BUREAU OF STANDARDS
C      WASHINGTON, D.C. 20234
C      (301) 921-2631
C
C      VERSION 1     DECEMBER 1979
C      UPDATE  1     MARCH    1980
C
C-------------------------------------------------------------------------
C
C  CODE.
C
      REAL PAM(10), PTT(10), PAD(20), PTD(20), AMHV(20000), AMDN(20000),
     *     BUFFER(2500), HVCPB(501)
      REAL VCUT, DELHV, DUMMY, CPROB, PROB, LVI, RVI, TEMP
      INTEGER NAM(10), HVICNT(501)
      INTEGER SIU, SOU, PLEVEL, MXNHVD, NHVI, NIAM, NTT, NAD, NTD,
     *        NHVIP1, I, NHV, TNHV, NDWH, DELNHV, IX, NHVD, DN, JTD,
     *        JAD, JTT, IAM, TNEVNT, ND, BUFPNT, BUFSZE, GPSEQN,
     *        PNEXT, PLAST, L1, L2, L3, L4
C
      INTEGER I1MACH
C
      INTEGER MXBFSZ, MXNHV
C
      DATA MXBFSZ /  2500/,
     *     MXNHV  / 20000/
C
      SIU = I1MACH(1)
      SOU = I1MACH(2)
C
C  -----
C  INPUT PARAMETERS TO SPECIFY HOW TO PROCESS THE DATA AND OUTPUT THE
C  ----- RESULTS.
C
      READ (SIU, 1100) PLEVEL, VCUT, MXNHVD, DELHV, NHVI
 1100 FORMAT (I2, E12.5, I12, E12.5, I12)
C
C  GET THE NUMBER OF ACTUAL MISSILES AND PROBABILITY OF OCCURRENCE
C  ARRAYS.
C
      CALL GETPRB (PLEVEL, NIAM, NAM, PAM, NTT, PTT, NAD, PAD, NTD, PTD)
C
C  INITIALIZATIONS.
C
      NHVIP1 = NHVI + 1
      DO 1200 I = 1, NHVIP1
         HVICNT(I) = 0
         HVCPB(I) = 0.0
 1200 CONTINUE
C
      NHV = 0
      TNHV = 0
      NDWH = 0
C
      PNEXT = 0
      PLAST = 0
C
      BUFPNT = 0
      BUFSZE = 0
C
C  LOOP 0, PROCESS EACH DISTRIBUTION.
C
 1300 CALL GETHVD (PLEVEL, MXNHV, NHV, PNEXT, PLAST, AMDN, AMHV, DELNHV,
     *             BUFPNT, MXBFSZ, BUFSZE, BUFFER)
      IF (DELNHV .EQ. 0) GO TO 1600
         NDWH = NDWH + 1
C
C  UPDATE THE HIT VELOCITY HISTOGRAM.
C
         DO 1400 I = 1, DELNHV
            IX = INT (AMHV(NHV + I) / DELHV) + 1
            IF (IX .GT. NHVI) IX = NHVIP1
```

```
          HVICNT(IX) = HVICNT(IX) + 1
 1400   CONTINUE
C
C UPDATE THE HIT VELOCITY CUMULATIVE PROBABILITY HISTOGRAM.
C
        IX = INT (AMHV(NHV + 1) / DELHV) + 1
        IF (IX .GT. NHVI) IX = NHVIP1
        DN = IFIX (AMDN(NHV + 1))
        CALL HPROB (DN, NIAM, PAM, NTT, PTT, NAD, PAD, NTD, PTD, IAM,
     *              JTT, JAD, JTD, PROB)
        DO 1450 1 = 1, IX
          HVCPB(I) = HVCPB(I) + PROB
 1450   CONTINUE
C
        TNHV = TNHV + DELNHV
C
C THE LARGEST HIT VELOCITY MUST BE SINGLED OUT FOR LATER SPECIAL
C TREATMENT.
C
        AMDN(NHV + 1) = - AMDN(NHV + 1)
C
C UPDATE THE NUMBER OF HIT VELOCITIES AND THEN DECREMENT IT UNTIL THE
C HIT VELOCITY CUTOFF IS SATISFIED.
C
        NHV = NHV + DELNHV
        DO 1500 I = 1, DELNHV
          IF (AMHV(NHV) .GE. VCUT) GO TO 1300
          NHV = NHV - 1
 1500   CONTINUE
        GO TO 1300
C
C SORT ALL THE HIT VELOCITIES IN DECREASING ORDER CARRYING ALONG THE
C MISSILE DISTRIBUTION NUMBERS.
C
 1600 IF (NHV .LE. 1) GO TO 1650
      CALL SSORT (AMHV, AMDN, DUMMY, DUMMY, NHV, - 2)
C
C RUN THROUGH THE SORTED LIST IN ORDER AND INTERCHANGE ENTRIES SUCH
C THAT ANY GROUP OF EQUAL VELOCITIES WHEN DECENDING THROUGH THE LIST
C START WITH ALL THE ENTRIES WITH NEGATIVE AMDN VALUES.
C
        DO 1625 I = 2, NHV
          J = I
 1610     IF ((AMHV(J - 1) .NE. AMHV(J)) .OR.
     *       (SIGN (1.0, AMDN(J - 1)) .LE. SIGN (1.0, AMDN(J))))
     *       GO TO 1625
C
            TEMP = AMHV(J - 1)
            AMHV(J - 1) = AMHV(J)
            AMHV(J) = TEMP
            TEMP = AMDN(J - 1)
            AMDN(J - 1) = AMDN(J)
            AMDN(J) = TEMP
            J = J - 1
            IF (J .GE. 2) GO TO 1610
 1625   CONTINUE
C
C ------
```

```
C  OUTPUT THE HIT ORDERING WITH PROBABILITIES.
C  ------
C
 1650 NHVD = MIN (NHV, MXNHVD)
      WRITE (SOU, 1700)
 1700 FORMAT (9H0(P-MAIN) / 1H , 3X, 18HHIT ORDERING WITH ,
     *         13HPROBABILITIES / 1H0, 3X, 5X, 1HI, 3X, 3HIAM, 3X, 3HJTT,
     *         3X, 3HJAD, 3X, 3HJTD, 7X, 5HHV(I), 13X, 7HPROB(I), 2X,
     *         18HPROB(V .GE. HV(I)), 1X, 6HGPSEQN)
C
      IF (NHVD .GT. 0) GO TO 1750
         IF (TNHV .NE. 0) GO TO 1720
            WRITE (SOU, 1710)
 1710       FORMAT (1H0, 6X, 7H------- / 1H , 6X, 7HNO HITS / 1H , 6X,
     *               7H-------)
            GO TO 1950
 1720    WRITE (SOU, 1730)
 1730    FORMAT (1H0, 6X, 14H-------------- / 1H , 6X,
     *               14HNO HITS LISTED / 1H , 6X, 14H--------------)
         GO TO 1950
C
 1750 CPROB = 0.0
      GPSEQN = 1
C
      DO 1900 I = 1, NHVD
C
C  DETERMINE THE INDICES TO THE PROBABILITY OF OCCURRENCE ARRAYS AND
C  THE EVENT PROBABILITY. UPDATE THE CUMULATIVE PROBABILITY IF THE
C  DISTRIBUTION NUMBER HAS BEEN SET NEGATIVE.
C
         DN = IABS (IFIX (AMDN(I)))
         CALL HPROB (DN, NIAM, PAM, NTT, PTT, NAD, PAD, NTD, PTD, IAM,
     *               JTT, JAD, JTD, PROB)
         IF (IFIX (AMDN(I)) .LT. 0) CPROB = CPROB + PROB
         IF ((I .GT. 1) .AND. (AMHV(I - 1) .NE. AMHV(I)))
     *      GPSEQN = GPSEQN + 1
C
         WRITE (SOU, 1800) I, IAM, JTT, JAD, JTD, AMHV(I), PROB, CPROB,
     *                     GPSEQN
 1800    FORMAT (1H , 3X, 5I6, 1PE12.5, 2(1PE20.5), 1X, I6)
 1900 CONTINUE
C
C  DETERMINE THE TOTAL NUMBER OF EVENTS AND UPDATE THE HIT VELOCITY
C  INTERVAL THAT INCLUDES ZERO WITH THE NUMBER OF NONHITS.
C
 1950 TNEVNT = 0
      DO 2000 I = 1, NIAM
         TNEVNT = TNEVNT + NAM(I)
 2000 CONTINUE
      TNEVNT = (NTT * NAD * NTD) * TNEVNT
      HVICNT(1) = HVICNT(1) + (TNEVNT - TNHV)
C
C  SET THE PROBABILITY OF THE FIRST INTERVAL (WHICH INCLUDES 0.0) OF THE
C  HIT VELOCITY CUMULATIVE PROBABILITY HISTOGRAM TO THE TOTAL.
C
      HVCPB(1) = 0.0
      DO 2010 L1 = 1, NIAM
         DO 2020 L2 = 1, NTT
```

```
            DO 2030 L3 = 1, NAD
               DO 2040 L4 = 1, NTD
                  HVCPB(1) = HVCPB(1) + PAM(L1) * PTT(L2) *
     *                                  PAD(L3) * PTD(L4)
 2040          CONTINUE
 2030       CONTINUE
 2020    CONTINUE
 2010 CONTINUE
C
C  ------
C  OUTPUT THE HIT VELOCITY HISTOGRAM AND THE HIT VELOCITY CUMULATIVE
C  ------ PROBABILITY HISTOGRAM.
C
      WRITE (SOU, 2100)
 2100 FORMAT (9H0(P-MAIN) / 1H , 3X, 22HHIT VELOCITY HISTOGRAM / 1H0,
     *        3X, 8X, 17HVELOCITY INTERVAL / 1H , 3X, 8X, 4HLEFT, 8X,
     *        5HRIGHT, 3X, 16HNUMBER OF EVENTS, 3X,
     *        17HPROB(V .GE. LEFT))
C
      DO 2300 I = 1, NHVI
         LVI = FLOAT (1 - I) * DELHV
         RV1 = FLOAT (1) * DELHV
C
         WRITE (SOU, 2200) LVI, RVI, HVICNT(I), HVCPB(I)
 2200    FORMAT (1H , 3X, 1PE12.5, 1X, 1PE12.5, 7X, I12, 8X, 1PE12.5)
 2300 CONTINUE
C
      LVI = RVI
      WRITE (SOU, 2400) LVI, HVICNT(NHVIPI), HVCPB(NHV1P1)
 2400 FORMAT (1H , 3X, 1PE12.5, 13X, 7X, I12, 8X, 1PE12.5)
C
C  ------
C  OUTPUT SUMMARY INFORMATION.
C  ------
C
      ND = N1AM * NTT * NAD * NTD
C
      WRITE (SOU, 2500) TNHV, NDWH, ND
 2500 FORMAT (9H0(P-MAIN) / 1H , 3X, 19HSUMMARY INFORMATION / 1H0, 3X,
     *        42HTOTAL NUMBER OF HITS                    = , I12 / 1H ,
     *        3X, 42HTOTAL NUMBER OF DISTRIBUTIONS WITH HITS = , I12
     *        / 1H , 3X, 42HTOTAL NUMBER OF DISTRIBUTIONS           = ,
     *        I12)
C
      STOP
      END
END PRT

@PRT,S PTORWDF-DOC.MARKEDDATA2/CASES
```

```
SIMIU*)*PTCRWDF-DOC(1).MARKEDDATA2/CASE5(0)
     1        1) MAIN    <C1   ,L1   >-1         100.0            0           1.0           100
  END PRT

@PRT,S PTCRWDF-DOC.DATA2/CASE5
```

```
SIMIUS)*PTORWDF-DOC(1).DATA2/CASE5(0)
     1       -1         100.0             0            1.0           100
  END PRT

@HDG.N .L.0
```

```
@XQT PTORWDF-DOC.STG2

 (P-MAIN)
    HIT ORDERING WITH PROBABILITIES

         I    IAM    JTT    JAD    JTO          HV(I)                PROB(I)  PROB(V .GE. HV(I)) GPSEQN

       --------------
       NO HITS LISTED
       --------------

 (P-MAIN)
    HIT VELOCITY HISTOGRAM

            VELOCITY INTERVAL
            LEFT          RIGHT   NUMBER OF EVENTS   PROB(V .GE. LEFT)
      0.00000       1.00000+00               4502          1.00000+00
      1.00000+00    2.00000+00                  0          6.60000-01
      2.00000+00    3.00000+00                  0          6.60000-01
      3.00000+00    4.00000+00                  0          6.60000-01
      4.00000+00    5.00000+00                  0          6.60000-01
      5.00000+00    6.00000+00                  0          6.60000-01
      6.00000+00    7.00000+00                  0          6.60000-01
      7.00000+00    8.00000+00                  0          6.60000-01
      8.00000+00    9.00000+00                  0          6.60000-01
      9.00000+00    1.00000+01                  0          6.60000-01
      1.00000+01    1.10000+01                  0          6.60000-01
      1.10000+01    1.20000+01                  0          6.60000-01
      1.20000+01    1.30000+01                  0          6.60000-01
      1.30000+01    1.40000+01                  0          6.60000-01
      1.40000+01    1.50000+01                  0          6.60000-01
      1.50000+01    1.60000+01                  0          6.60000-01
      1.60000+01    1.70000+01                  0          6.60000-01
      1.70000+01    1.80000+01                  0          6.60000-01
      1.80000+01    1.90000+01                  0          6.60000-01
      1.90000+01    2.00000+01                  0          6.60000-01
      2.00000+01    2.10000+01                  0          6.60000-01
      2.10000+01    2.20000+01                  0          6.60000-01
      2.20000+01    2.30000+01                  0          6.60000-01
      2.30000+01    2.40000+01                  0          6.60000-01
      2.40000+01    2.50000+01                  0          6.60000-01
      2.50000+01    2.60000+01                  1          6.60000-01
      2.60000+01    2.70000+01                  2          6.60000-01
      2.70000+01    2.80000+01                  8          6.60000-01
      2.80000+01    2.90000+01                  3          6.60000-01
      2.90000+01    3.00000+01                 18          6.60000-01
      3.00000+01    3.10000+01                 13          6.60000-01
      3.10000+01    3.20000+01                  3          6.60000-01
      3.20000+01    3.30000+01                 17          6.60000-01
      3.30000+01    3.40000+01                 20          6.60000-01
      3.40000+01    3.50000+01                 46          6.60000-01
      3.50000+01    3.60000+01                 55          6.60000-01
      3.60000+01    3.70000+01                 55          6.60000-01
      3.70000+01    3.80000+01                 42          6.60000-01
      3.80000+01    3.90000+01                 38          6.60000-01
      3.90000+01    4.00000+01                 33          6.00000-01
      4.00000+01    4.10000+01                 33          6.00000-01
```

```
4.10000+01    4.20000+01                  18          6.00000-01
4.20000+01    4.30000+01                  23          5.40000-01
4.30000+01    4.40000+01                  14          4.80000-01
4.40000+01    4.50000+01                  16          4.80000-01
4.50000+01    4.60000+01                  10          3.60000-01
4.60000+01    4.70000+01                   8          3.60000-01
4.70000+01    4.80000+01                   6          3.60000-01
4.80000+01    4.90000+01                   5          3.60000-01
4.90000+01    5.00000+01                   4          3.00000-01
5.00000+01    5.10000+01                   6          2.40000-01
5.10000+01    5.20000+01                   1          2.40000-01
5.20000+01    5.30000+01                   6          2.40000-01
5.30000+01    5.40000+01                   1          6.00000-02
5.40000+01    5.50000+01                   1          6.00000-02
5.50000+01    5.60000+01                   0          0.00000
5.60000+01    5.70000+01                   0          0.00000
5.70000+01    5.80000+01                   0          0.00000
5.80000+01    5.90000+01                   0          0.00000
5.90000+01    6.00000+01                   0          0.00000
6.00000+01    6.10000+01                   0          0.00000
6.10000+01    6.20000+01                   0          0.00000
6.20000+01    6.30000+01                   0          0.00000
6.30000+01    6.40000+01                   0          0.00000
6.40000+01    6.50000+01                   0          0.00000
6.50000+01    6.60000+01                   0          0.00000
6.60000+01    6.70000+01                   0          0.00000
6.70000+01    6.80000+01                   0          0.00000
6.80000+01    6.90000+01                   0          0.00000
6.90000+01    7.00000+01                   0          0.00000
7.00000+01    7.10000+01                   0          0.00000
7.10000+01    7.20000+01                   0          0.00000
7.20000+01    7.30000+01                   0          0.00000
7.30000+01    7.40000+01                   0          0.00000
7.40000+01    7.50000+01                   0          0.00000
7.50000+01    7.60000+01                   0          0.00000
7.60000+01    7.70000+01                   0          0.00000
7.70000+01    7.80000+01                   0          0.00000
7.80000+01    7.90000+01                   0          0.00000
7.90000+01    8.00000+01                   0          0.00000
8.00000+01    8.10000+01                   0          0.00000
8.10000+01    8.20000+01                   0          0.00000
8.20000+01    8.30000+01                   0          0.00000
8.30000+01    8.40000+01                   0          0.00000
8.40000+01    8.50000+01                   0          0.00000
8.50000+01    8.60000+01                   0          0.00000
8.60000+01    8.70000+01                   0          0.00000
8.70000+01    8.80000+01                   0          0.00000
8.80000+01    8.90000+01                   0          0.00000
8.90000+01    9.00000+01                   0          0.00000
9.00000+01    9.10000+01                   0          0.00000
9.10000+01    9.20000+01                   0          0.00000
9.20000+01    9.30000+01                   0          0.00000
9.30000+01    9.40000+01                   0          0.00000
9.40000+01    9.50000+01                   0          0.00000
9.50000+01    9.60000+01                   0          0.00000
9.60000+01    9.70000+01                   0          0.00000
9.70000+01    9.80000+01                   0          0.00000
9.80000+01    9.90000+01                   0          0.00000
```

```
      9.90000+01    1.00000+02                      0            0.00000
      1.00000+02                                    0            0.00000

  (P-MAIN)
     SUMMARY  INFORMATICN

     TCTAL  NUMBER  OF  HITS                        =          506
     TOTAL  NUMBER  OF  DISTRIBUTIONS  WITH  HITS  =           11
     TOTAL  NUMBER  OF  DISTRIBUTICNS               =           16

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☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

A procedure was developed for estimating speeds with which postulated missiles hit any given set of targets in a nuclear power plant or similar installation. Hit speeds corresponding to probabilities of occurrence of 10^{-7} were calculated for a given nuclear power plant under various assumptions concerning the magnitude of the force opposing missile take-off, direction of tornado axis of translation, number and location of missiles, and size of target area. The results of the calculations are shown to depend upon the parameters: C_DA/m, where C_D = drag coefficient, A = projected area, m = mass of missiles, and the ratio, k, between the minimum aerodynamic force required to cause missile take-off, and the weight of the missile.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Missiles; engineering; structural engineering; tornadoes; wind.

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